

NASA Technical Memorandum 4459

1N-89

157836

P-142

Reports of Planetary Astronomy—1992

MARCH 1993

(NASA-TM-4459) REPORTS OF
PLANETARY ASTRONOMY - 1991 (NASA)
142 p

N93-23055

Unclass

H1/89 0157836

NASA



NASA Technical Memorandum 4459

Reports of Planetary Astronomy—1992

Jurgen Rahe, *Editor*
NASA Office of Space Science and Applications
Washington, D.C.



National Aeronautics and
Space Administration
Office of Management
Scientific and Technical
Information Program

1993

PREFACE

This publication is a compilation of summaries of reports written by Principal Investigators funded through the Planetary Astronomy Program of NASA's Solar System Exploration Division, Office of Space Science and Applications.

The summaries are designed to provide information about current scientific research projects conducted in the Planetary Astronomy Program in 1991, and to facilitate communication and coordination among scientists in universities, government, and industry.

The reports are published as they were submitted by the Principal Investigators and are virtually unedited. They are arranged in alphabetical order.

In a second section, highlights of recent accomplishments in planetary astronomy are summarized as they were submitted by the Principal Investigators. The name attached to an individual paragraph is generally the name of the person who submitted that paragraph.

Jurgen Rahe
Discipline Scientist
Planetary Astronomy Program
Solar System Exploration Division

1992

PRECEDING PAGE BLANK NOT FILMED

CONTENTS

Preface	iii
List of Principal Investigators	vii
List of Highlights of Recent Accomplishments	xv
Summaries of Research Projects	1
Highlights of Recent Accomplishments	111

PRECEDING PAGE BLANK NOT FILMED_v

PAGE 1 ✓ INTENTIONALLY BLANK

LIST OF PRINCIPAL INVESTIGATORS

<u>Name</u>	<u>Organization</u>	<u>Title</u>	<u>Page</u>
Michael F. A'Hearn	University of Maryland	Observations of Comets and Asteroids	1
Michael F. A'Hearn	University of Maryland	Theoretical Spectroscopy of Comets	4
Frank N. Bash	University of Texas McDonald Observatory	McDonald Observatory Support (no report submitted)	-
Reta Beebe	New Mexico State University	Long Term Changes in Reflectivity and Large Scale Motions in the Atmosphere of Jupiter and Saturn	6
Jefferey F. Bell	University of Hawaii	Infrared Spectral Studies of Asteroids (no report submitted)	-
Michael J.S. Belton	National Optical Astronomy Observatories	Analysis and Interpretation of CCD data on P/Halley and Physical Parameters	8
Richard P. Binzel	Massachusetts Institute of Technology	Spectroscopic Survey of Small Main-Belt Asteroids	9
Edward Bowell	Lowell Observatory	Studies of Asteroids and Comets	11
John C. Brandt	University of Colorado	Plasma Structures in Comets (no report submitted)	-
Robert H. Brown	Jet Propulsion Laboratory	IR Observations of Small Solar System Bodies (no report submitted)	-
Marc W. Buie	Lowell Observatory	Albedo and Compositional mapping of Pluto and Charon (no report submitted)	-
Donald B. Campbell	Cornell University	Arecibo S-Band Radar Program	14

<u>Name</u>	<u>Organization</u>	<u>Title</u>	<u>Page</u>
Clark R. Chapman	Planetary Science Institute	Planetary Astronomy (No Report Submitted)	-
Anita L. Cochran	University of Texas McDonald Observatory	Physical Observations of Comets: Their Composition, Origin and Evolution	16
William D. Cochran	University of Texas McDonald Observatory	Radial Velocity Detection of Extra-Solar Planetary Systems	18
Dale P. Cruikshank	Ames Research Center	Volatiles in the Outer Solar System	20
Drake Deming	Goddard Space Flight Center	Advanced IR Astronomy: Extra- solar Planet Detection; Thermal Waves (no report submitted)	-
Edward W. Dunham	Ames Research Center	Stellar Occultations in the 1990's: Portable, High-Speed, CCD Photometers	22
James L. Elliot	Massachusetts Institute of Technology	The Atmospheres of Pluto and Triton: Occultation Studies	23
Uwe Fink	University of Arizona	Planetary Spectroscopy	25
Margaret A Frerking	Jet Propulsion Laboratory	Submillimeter Wave Planetary Observation Development	27
George D Gatewood	University of Pittsburgh	Search for Planetary Systems (no report submitted)	-
Tom Gehrels	University of Arizona	Surveying the Solar System	29
Robert D. Gehrz	University of Minnesota	IR Photometry and Spectroscopy of Bright Comets (no report submitted)	-
Jay D. Goguen	Jet Propulsion Laboratory	1991 Io Occultations: Observing and Data Analysis	31

<u>Name</u>	<u>Organization</u>	<u>Title</u>	<u>Page</u>
Samuel Gulkis	Jet Propulsion Laboratory	Planetary Submillimeter Astronomy	33
Donald N. B. Hall	University of Hawaii	Operation of 88" for Planetary Astronomy at Mauna Kea (no report submitted)	-
Donald N. B. Hall	University of Hawaii	IRTF Operation (no report submitted)	-
Martha S. Hanner	Jet Propulsion Laboratory	Infrared Observations of Cometary Dust	35
Alan W. Harris	Jet Propulsion Laboratory	Asteroid Photometry	37
Wm. K. Hartmann	Planetary Science Institute	Outer Solar System Small Bodies and Related Objects (no report submitted)	-
Eleanor F. Helin	Jet Propulsion Laboratory	Palomar Planet-Crossing Asteroid Survey (PCAS)	39
Robert R. Howell	University of Wyoming	Infrared Speckle Interferometry and Spectroscopy of Io	41
William B. Hubbard	University of Arizona	Interiors and Atmospheres of the Outer Planets	43
Donald M. Hunten	University of Arizona	Studies of Extended Planetary Atmospheres	45
William M. Jackson	University of California Davis	Laser Studies of the Photo-dissociation Dynamics for the Formation of Cometary Radicals	47
William M. Jackson	University of California Davis	Laboratory Simulation of the Surface of Halley's Comet	48

<u>Name</u>	<u>Organization</u>	<u>Title</u>	<u>Page</u>
Donald E. Jennings	Goddard Space Flight Center	Ground Based IR Astronomy (no report submitted)	-
David Jewitt	University of Hawaii	Physical Properties of Active Comets	49
Torrence V. Johnson	Jet Propulsion Laboratory	IR Observations of Outer Planetary Satellites (no report submitted)	-
Raymond F. Jurgens	Jet Propulsion Laboratory	Goldstone Solar System Radar	50
Roger Knacke	Penn State University	Infrared Spectroscopy of Jupiter and Saturn	52
Theodor Kostiuk	Goddard Space Flight Center	Advanced Infrared Astronomy	54
Stephen Larson	University of Arizona	Imaging and Spectroscopic Studies of Primitive Solar System Bodies	56
Larry A. Lebofsky	University of Arizona	Infrared Observations of Solar System Objects	58
Barry L. Lutz	Lowell Observatory	Solar System Spectroscopy	60
Brian G. Marsden	Smithsonian Institution Astrophysical Observatory	Astrometric Observations of Comets and Asteroids and Subsequent Orbital Investigations	62
Dennis Matson	Jet Propulsion Laboratory	Asteroid Research (no report submitted)	-
Robert S. McMillan	University of Arizona	The Radial Velocity Search for Extrasolar Planets	64
Karen J. Meech	University of Hawaii	Observational Evidence for Aging in Comets (no report submitted)	-

<u>Name</u>	<u>Organization</u>	<u>Title</u>	<u>Page</u>
Robert L. Millis	Lowell Observatory	Occultation Studies of the Solar System	66
Duane O. Muhleman	California Institute of Technology	Planetary Studies	68
Duane O. Muhleman	California Institute of Technology	Planetary Radar Astronomy Using the Very Large Array	71
Michael J. Mumma	Goddard Space Flight Center	Investigation of Comets at IR Wavelengths	74
Marcia Neugebauer	Jet Propulsion Laboratory	Study of Cometosheath Composition and Dynamics Using Data Obtained by the Giotto Ion Mass Spectrometer	77
Ray Newburn, Jr.	Jet Propulsion Laboratory	Physical Processes in Comets	78
Malcolm B. Niedner	Goddard Space Flight Center	Imaging Studies of Comets (no report submitted)	-
Glenn S. Orton	Jet Propulsion Laboratory	Infrared Observations of Planetary Atmospheres	80
Steven J. Ostro	Jet Propulsion Laboratory	Radar Investigation of Asteroids and Planetary Satellites	82
Toby C. Owen	University of Hawaii	Spectroscopic Observations of Outer Planets	84
Carolyn C. Porco	University of Arizona	Stellar Occultations of Planetary Rings (no report submitted)	-
Andrew Potter	Johnson Space Center	Exospheres of the Moon and Mercury	87
David G. Schleicher	Lowell Observatory	Ground-Based Cometary Studies	89

<u>Name</u>	<u>Organization</u>	<u>Title</u>	<u>Page</u>
F. Peter Schloerb	University of Mass.	Radiative Transfer in Planetary Atmospheres (no report submitted)	-
Nicholas Schneider	University of Colorado	Imaging and Spectroscopy of Io's Torus and Atmosphere	91
Irwin I. Shapiro	Smithsonian Institution Astrophysical Observatory	Radar Studies in the Solar System	93
Bradford A. Smith	University of Hawaii	Studies in Planetary Science (no report submitted)	-
Lewis E. Snyder	University of Illinois	Radio Interferometric Studies of Comets	94
John R. Spencer	Lowell Observatory	Monitoring Io's Volcanos with Infrared Imaging	96
Hyron Spinrad	University of California Berkeley	New Directions in Cometary Spectroscopy	98
Steven E. Strom	University of Mass.	Stellar Disks and Environment (no report submitted)	-
Richard J. Terrile	Jet Propulsion Laboratory	Planetary Optical and Infrared Imaging (no report submitted)	-
David J. Tholen	University of Hawaii Institute for Astronomy	Monitoring and Modeling of the Pluto-Charon System	99
David J. Tholen	University of Hawaii Institute for Astronomy	Observations of Spacecraft Targets, Unusual Objects, and Other Targets of Opportunity	101
Larry Trafton	University of Texas	Ground-Based Studies of the Outer Planets	103
Faith Vilas	Johnson Space Center	Compositional Studies of Primitive Asteroids	105

<u>Name</u>	<u>Organization</u>	<u>Title</u>	<u>Page</u>
James G. Williams	Jet Propulsion Laboratory	Astrometric Observations of Comets and Minor Planets	106
Wieslaw Wisniewski	University of Arizona	Physical Studies of Small Asteroids, Cometary Cores, and Galileo Targets 243 Ida and 951 Gaspra	107
Susan Wyckoff	Arizona State University	Cosmochemistry of Comets (no report submitted)	-
Donald K. Yeomans	Jet Propulsion Laboratory	Comet and Asteroid Dynamics	109

HIGHLIGHTS OF RECENT ACCOMPLISHMENTS

<u>Title</u>	<u>PI Name</u>	<u>Page</u>
Ices on Neptune's Satellite Triton	D. P. Cruikshank	113
Discovery of Solar-System Objects by CCD Scanning	T. Gehrels	114
Palomar Planet-Crossing Asteroid Survey (PCAS)	F. Helin	115
A Detailed Map of Titan's Stratosphere from Stellar Occultation	W. B. Hubbard	116
Plasma Flow in the Coma of Comet Halley	M. Neugebauer	117
Infrared Observations of Planetary Atmospheres	G. S. Orton	118
High-Resolution Radar Ranging to Near-Earth Asteroids	S. J. Ostro	119
Near-Infrared Windows in Titan's Atmosphere	T. Owen	120
Sodium and Potassium in the Lunar Atmosphere	A. E. Potter	121
Fast 'Jets' from Io's Atmosphere Explained	N. M. Schneider	122
Radar Studies in the Solar System	I. Shapiro	123
Bistatic Radar Observations of Asteroids	E. Snyder	124
High-Resolution Infrared Imaging of Io's Volcanic Activity	J. R. Spencer	125
Extraordinary Colors of (5145) 1992 AD	D. J. Tholen	126
Ground-based Observations Provide Preview of Galileo Encounter with Gaspra	D. J. Tholen	127
Discovery of H ₃ ⁺ on Uranus	L. Trafton	128
Compositional Studies of Primitive Asteroids	F. Vilas	129
The Use of Radar Data for Improving the Ephemerides of Asteroids and Comets	D. K. Yeomans	130

Observations of Comets and Asteroids

Astronomy Program
University of Maryland
College Park, MD

Michael F. A'Hearn

(Co-Investigators J.J. Klavetter and N. H. Samarasinha)

Strategy

We use all available ground-based observational techniques to study the chemical and physical properties of the small bodies of the solar system, primarily comets and secondarily asteroids. The ultimate goal is to use these bodies to understand the formation and evolution of the solar system. Because of a large accumulation of data, we place at least as much emphasis on analyzing existing data as we do on obtaining new data.

Progress and Accomplishments

- i) J. J. Klavetter and S. Hoban (GSFC), completed the analysis of images of comet Levy through a narrow-band filter centered on the 3.4-micron emission feature. They showed that the spatial profile of this feature is identical to that of the dust, thus showing that the carrier is either a form of dust grain or a long-lived gaseous molecule released from the nucleus and that it is not a gaseous daughter product.
- ii) Photometric observations of comets which are likely targets of spacecraft, obtained over the past decade by M. F. A'Hearn and various collaborators, were pulled together, reduced, and published (by Osip and Schleicher). These observations provide the fundamental data on gaseous densities necessary to design missions to these comets.
- iii) J. J. Klavetter and M. F. A'Hearn completed their analysis of the motion of CN jets in CCD images of comet P/Halley. The velocities projected on the sky cover a wide range due to projection effects but, more importantly, the velocities extend up to 1.7 km/sec (normalized to heliocentric distance 1 AU) implying that the carriers of the distributed source of CN are moving much faster than the bulk of the material in the coma.

- iv) J. J. Klavetter and M. F. A'Hearn began an analysis of the distribution of the CN production. Preliminary results suggest that after one removes an isotropic component, whether empirically or with a Haser model, the residual source (primarily in the jets) has a radial distribution of production rate similar to that found for CO using *in situ* data.
- v) N. H. Samarasinha and M. F. A'Hearn completed their analysis of the constraints on P/Halley's rotation based on our ccd images. Their conclusions complement those of Belton et al. The latter showed that a LAM with $P(\text{rot})=7.4$ days and $P(\text{prec})=3.7$ days would fit even more datasets than we used while we showed that nearly all other modes, particularly all SAM modes, would not fit the constraints.
- vi) M. F. A'Hearn collaborated with D. Jewitt and H. Campins to study the nucleus of comet P/Faye using IRTF/UH-88/IUE simultaneously. Although the observations were successful, it appears that the nucleus was too faint relative to the dusty coma to be separable.
- vii) M. F. A'Hearn collaborated with D. Schleicher in improving the algorithms for reducing filter photometric data on comets. These improvements should reduce the scatter in abundance ratios and enable a cleaner interpretation of abundance ratios.
- viii) Initiated program to search for OH emission from 'wet' asteroids using UH 88-inch with T. Owen. One scheduled run terminated due to death of uv-sensitive ccd at UH.

Projected Accomplishments

- i) Continue analysis of radial profile of CN emission in comets.
- ii) Observe Oljato to search for cometary emissions as tentatively reported many years ago by McFadden.
- iii) Observe Ceres to follow up on IUE results suggesting outgassing and escape of OH. (time scheduled at ESO).
- iv) Continue analysis of 14-year narrow-band photometric program.
- v) Compare ccd images of various comets for correlation between presence of structures in coma with dynamical age and for relationship between jet structures and shell structures.

Publications

A'Hearn, M.F. (1991). Looking for Relationships, *Nature* **347**, 715-716. (News&Views)

A'Hearn, M.F. (1991). Views of a Comet, *Science*, **252**, 998-999. (book review)

A'Hearn, M.F. (1992). Cometary Chemistry, in "Astrochemistry of Cosmic Phenomena", IAU Symposium, Campos do Jordao, SP Brazil, in press.

(Invited Review) Bus, S.J. M.F. A'Hearn, D.G. Schleicher, and E. Bowell (1991). Detection of CN Emissions from (2060) Chiron, *Science*, **251**, 774-777.

Klavetter, J.J. and M.F. A'Hearn (1991). CN Jet Expansion Velocity in Comet P/Halley, *Icarus*, **95**, 73-85.

Klavetter, J.J. and S. Hoban (1992). Imaging the 3.4 μ m Feature in Comet Levy (1990), *Icarus*, **95**, 60-64.

Samarasinha, N.H. (1992). Inhomogeneities of Spatial and Temporal Variations of Comets, Ph.D. Thesis, University of Maryland.

Samarasinha, N.H., and M.F. A'Hearn (1991). Observational and Dynamical Constraints on the Rotation of Comet P/Halley, *Icarus*, **93**, 194-225.

Theoretical Spectroscopy of Comets

Astronomy Program
University of Maryland
College Park, MD

Michael F. A'Hearn

Strategy

We calculate theoretical spectra of various emitting species in cometary comae both to investigate physical parameters that are measurable with cometary spectra and to provide fluorescence efficiencies for the derivation of abundances from fluxes.

Progress and Accomplishments

- i) Completed a study of SH, the predicted dissociation product of H_2S which has recently been detected at radio wavelengths. Because of its short lifetime, SH is difficult to detect. Upper limits from available ground-based spectra are about 1% of water, significantly higher than the observed H_2S . Calculated spectra of CH for comparison with spectra obtained by Brown and Spinrad. The short lifetime of CH prevents it from reaching fluorescent equilibrium. Current calculations use a thermal population distribution to represent the unknown distribution formed when CH is produced by photodissociation from its parent. Spectra appear to fit both the B-X and A-X systems, although the interpretation of this fit is still uncertain.
- ii) Began calculations of the spectra of C_3 , CO_2^+ , and NH_2 . Results still incomplete because these triatomic molecules have very complex spectra. A new band of C_3 was recently discovered and is being considered in our calculations.

Anticipated Accomplishments

- i) Complete our study of the temporal variability of S_2 in IRAS-Araki-Alcock using ground-based spectra obtained by S. Larson (intended for 1991 but set aside because of other interesting problems).
- ii) Investigate carbon suboxide and its dissociation fragments to follow up suggestion by Huntress et al. that this is the distributed source of CO in comet P/Halley. Continue models for C_3 , CO_2^+ , and NH_2 for comparison with data of Brown & Spinrad.

Publications

A'Hearn, M.F. (1991). Cometary Chemistry, in "Astrochemistry of Cosmic Phenomena," IAU Symposium, Campos do Jordao, SP Brazil, in press.

(Invited Review) Kim, S.J. and M. F. A'Hearn (1991). Upper Limits of SO and SO_2 in Comets, *Icarus*, **90**, 79-95.

Kim, S.J. and M. F. A'Hearn (1992). G-Factors of the SH (0-0) Band and SH Upper Limit in Comet P/Brorsen-Metcalf (1980), submitted to *Icarus*.

Long-Term Changes in Reflectivity and Large Scale Motions in the Atmospheres of Jupiter and Saturn

Department of Astronomy
New Mexico State University
Las Cruces, New Mexico 88003-0001

Reta Beebe

Strategy

This is an observational program that utilizes a dedicated 60 cm. telescope, a CCD camera and multicolored filters to record photometrically calibrated temporal changes in the atmospheres of Jupiter and Saturn. The intent of this project is to maintain a continuous database that can be used to link the Voyager, Hubble Space Telescope (HST) and Galileo data sets.

Progress and Accomplishments

Detailed interpretation of Saturn's equatorial storm has been completed. Combining NMSU observations with HST data we have shown that the observed cloud patterns were the atmospheric response to a single eruptive perturbation. Photometrically calibrated multicolored images of Jupiter are being used to monitor the surface brightness in the 889 nm CH₄ band as well as with multicolored broadband filters. These data are being supplied to D. Kuehn at Pittsburg University, Pittsburg, Kansas and Glen Orton at Jet Propulsion Lab, Pasadena, California. Coordinated efforts are being made to integrate these data with Orton's IR data to provide stronger constraints on atmospheric models and understand the temporal behavior of the atmospheres. Translational drift rates are being used to assist in targeting HST observations. Encoding and archiving of the historical photographic record are continuing.

Anticipated Accomplishments

In May 1992 an extensive imaging and spectroscopic HST data set will be obtained. These data represent the same Jovian season as the Voyager data set. We will use the NMSU ground-based data to relate the HST and Voyager data by specifying activity in the intervening period.

Publications

R. Beebe, C. Barnet, P.V. Sada and A.S. Murrell, (1992) The Onset and Growth of the 1990 Equatorial Disturbance on Saturn, *Icarus*, **95**, 163-172.

C. Barnet, R. Beebe and B. Conrath, (1992) A Seasonal Radiative-Dynamic Model of Saturn's Troposphere, *Icarus*, in press.

D. Kuehn and R. Beebe, (1992) A Study of Time Variability of Jupiter's Atmospheric Structure, *Icarus*, Submitted.

C. Barnet, J. Westphal, R. Beebe and L. Huber, The 1990 Equatorial Storm on Saturn: Observations of Zonal Winds and Central Meridian Albedos with the Hubble Space Telescope, *Icarus*, in preparation.

Analysis and Interpretation of CCD data on P/Halley and Physical Parameters of Periodic Comets and Asteroids

Kitt Peak National Observatory
Tucson AZ 85726

Michael J.S. Belton and Beatrice Mueller

Strategy

The scientific objectives of this work are: (1) to obtain time-series with CCD-photometry of periodic comets specific asteroids suspect as extinct comets and near-Earth approachers; (2) to derive rotational periods of these objects; (3) to investigate the activity status of the comets at various distances from the Sun; (4) to compare the different groups with each other; (5) to refine Halley's spin model in order to get a precise ephemeris and a tool to disentangle rotation and activity effects; (6) to continue the investigation of 2060 Chiron.

Progress and Accomplishments

A definitive model for the basic spin state for comet P/Halley was completed and published. Our observing program got 9 runs at the 2.1m telescope at KPNO. All observations of 13 cometary and asteroidal objects have been reduced and part of the data was reported at the ACM meeting and published. During this observing program (5145) 1992 AD was discovered to be the reddest asteroidal object yet found. Our ongoing work focuses on (1) an interpretation of unusual colors of (5145) 1992 AD (Mueller et al.); (2) A detailed analysis of the pre-perihelion photometry of P/Halley in the context of our spin model; (3) The continued development of a computer code (MODELSIM) capable of tying together ground-based light-curve observations with spacecraft observations of comets and asteroids. The code is already successfully used in our analysis of data on P/Halley and 951 Gaspra.

Anticipated Accomplishments

We expect to (1) improve the spin ephemeris of P/Halley and perform a test whether the spin vector underwent any substantial change during the last apparition; (2) characterize the activity in this comet when it was at 8 AU pre-perihelion and determine the location of the region on the nucleus from which this activity originated; (3) separate the effects of rotation and activity in its light-curve when it was at 5 AU pre-perihelion which should allow us to definitively characterize the way the comet started its activity under stimulus of the sun; (4) test the often made assumption that an appreciable fraction of the coma gases (e.g. CO) are produced in an extended region in the coma from dust grains; (5) continue our ground-based observational and interpretational studies of the nuclear properties of selected asteroids and comets.

Spectroscopic Survey of Small Main-Belt Asteroids

Massachusetts Institute of Technology
Cambridge, MA

Richard P. Binzel

Strategy

The proposed research seeks to address two fundamental outstanding problems the link between planetary astronomy and solar system cosmochemistry:

- i) Dedicated studies of meteorite orbits and fall statistics, coupled with recent dynamical models, show that meteorites are derived from the asteroid belt. However, the most common meteorite type - the ordinary chondrites - have no known spectral analog in the main belt. Are our mineralogical interpretations of planetary spectra wrong? If not, then what is the source for ordinary chondrite meteorites?
- ii) Iron meteorites could only have originated in the cores of large internally heated asteroids, where these cores were surrounded by more voluminous olivine mantles. Subsequent collisions which liberated these iron cores to yield the presently observed metallic asteroids and iron meteorites should have also produced an even greater abundance of olivine-rich asteroids from the mantle fragments. However, olivine-rich asteroids are exceedingly rare. Are our basic models for planetary differentiation wrong? Are our models of asteroid collisional evolution wrong? If not, then where is the missing olivine mantle material?

Progress and Accomplishments

This work has been funded for six months. We have completed 3 observing runs with the Michigan- Dartmouth-MIT 2.4-m telescope and have observed more than 30 small main belt asteroids as well as target of opportunity near-Earth asteroids and the outer solar system asteroid 1992 AD. Final processing of these spectral data is underway.

Anticipated Accomplishments

Three to five observing runs (5-7 nights each) will be performed with the Michigan-Dartmouth-MIT 2.4-m telescope. We will continue to survey the compositional properties of small main-belt asteroids for comparison with larger main-belt asteroids and laboratory spectra of meteorites. After achieving sufficient statistics, we hope to address fundamental questions related to the formation and thermal evolution of the asteroids.

Publications

Binzel, R. P. and Xu, S. "1991 VK, 1991 VL, 1991 WA, 1992 XB." IAUC 5422 (1992).

Studies of Asteroids and Comets

Lowell Observatory
1400 W. Mars Hill Road
Flagstaff, AZ 86001

Edward Bowell

Strategy

Our work comprises observational, theoretical, and computational research, mainly on asteroids. Two principal areas of research, centering on astrometry and photometry, are interrelated in their aim to study the overall structure of the asteroid belt and the physical and orbital properties of individual asteroids.

Progress and Accomplishments

Much of our time has gone into modeling the orbital element distribution of near-Earth asteroids and comets, and thereby calculating their sky-plane distributions as a function of limiting magnitude. Such calculations led to the design of an observing strategy and to an evaluation of the telescope/detector requirements for a major proposed near-Earth object survey. A second major task has been to continue work on a new method of asteroid orbital error analysis based on Bayesian theory; much of an extensive publication has been prepared. Our observational work on the spin characteristics of small main-belt asteroids has been completed, and two papers thereon have been submitted for publication. Our study of Chiron's historical light variation is being brought to a conclusion. A paper on "photomorphography" (the determination of a spinning body's shape and albedo distribution from observed light-curves) has been submitted for publication; and related work, on the use of spherical harmonics to analyze asteroid light-curves, is well advanced. Observations of the light-curve of (5145)-1992-AD were made, as were CCD astrometric observations of faint asteroids (mainly Earth-approachers). We continued our prolific publication of asteroid positions from films taken at the 46-cm and 1.2-m Schmidt telescopes at Palomar, and from archival plates taken at Lowell and Goethe-Link Observatories. Many asteroid orbits have been calculated, and asteroid identification work has proceeded apace. We recently constructed a file of asteroid osculating elements, with entries every hundred days from 1890 through 2020. Parts of the file have been transmitted to a number of colleagues worldwide. In addition, the file has enabled us to identify asteroid images on given plates and to identify plates on which images of a given asteroid should be visible. In the latter context, we were able to measure pre-discovery images of (1862) Apollo.

Anticipated Accomplishments

We will explore ways of ramping up to the proposed Spaceguard Survey for near-Earth asteroids and comets. Our NEO modeling, incorporating a new method of correction for observational bias, will be completed for journal publication, and we will begin developing new software for the automatic detection of moving objects in CCD data. We hope also to start on the refurbishment of a disused 40-cm Schmidt telescope, to be devoted eventually to CCD searching for NEOs and main-belt asteroids. We will complete our studies of asteroid orbital error analysis, Chiron's historical brightness variations, spherical harmonics as applied to asteroid rotation, and the discovery and dynamical evolution of the Mars Trojan 1990-MB. CCD astrometry and photometry of selected asteroids will continue as before, and CCD astrometry of P/Grigg-Skjellerup will be carried out in support of the Giotto mission. Asteroid and comet astrometry and orbit and identification work on asteroids will also be continued, with some effort being expended on improving machine-readable archival plate logs. A search for Mars Trojans, using the UK Schmidt Telescope, will be undertaken this autumn.

Publications

- Bowell, E. (1991). [asteroid identifications]. *Minor Planet Circular* Nos. 17627, 17629, 17630, 17633, 17634, 17650, 17651, 17802, 17807, 17945, 17958, 17963, 17974, 18091, 18093, 18110, 18112, 18116, 18118, 18121, 18130, 18132, 18266, 18279-18281, 18283, 18291, 18295, 18299, 18444, 18445, 18780, 18784, 18801, 18805, 18806, 18808, 18809, 18812, 18813, 18832, 18834, 18835, 19003, 19010, 19011, 19020, 19298, 19328, and 19331.
- Bowell, E. (1991). [asteroid and comet observations]. *Minor Planet Circular* Nos. 17525, 17562, 17564, 17710, 17717, 17719, 18035, 18058-18060, 18184, 18206, 18207, 18337, 18348, 18350, 18514, 18561, 18562, 18564, 18616, 18617, 18619, 18622, 18625, 18678, 18741, 18882, 18917, 18918, and 19165.
- Bowell, E. (1991). [asteroid orbits]. *Minor Planet Circular* Nos. 17596-17598, 17601-17606, 17626, 17627, 17631, 17633-17637, 17651-17654, 17795-17802, 17808, 17809, 17816, 17817, 17827, 17949-17942, 17944, 17946, 17955, 17956, 17958, 17961, 17963, 17973-17978, 18082-18090, 18092, 18093, 18096, 18098, 18099, 18103-18109, 18111-18121, 18130, 18131-18134, 18260, 18261, 18264, 18269, 18279-18282, 18285, 18286, 18294, 18296, 18304, 18398, 18399, 18422, 18445, 18598-18607, 18609, 18616, 18617, 18620-18622, 18624, 18631, 18773-18780, 18786, 18787, 18801, 18802-18808, 18812, 18814, 18817, 18819, 18823, 18830, 18832, 18834, 18995-19001, 19011, 19013, 19014, 19018-19020, 19023, 19025, 19027, 19028, 19035, 19262, 19274, 19289, 19293, 19296, 19298, 19302, and 19331.
- Bowell, E. (1992). [asteroid and comet positions]. *IAU Circular* Nos. 5314, 5322, 5359, and 5493.
- Bowell, E. (1992). [asteroid identifications]. *Minor Planet Circular* Nos. 19502, 19658, 19660, 19662, 19663, 19665, 19668, 19671, 19689, 19830, 19833, 19839, 19852, 19855, 19858, 19861, 19881, 19882, 20008, 20014, 20018, 20019, 20026, and 20037.
- Bowell, E. (1992). [asteroid observations]. *Minor Planet Circular* Nos. 19406, 19435, 19437, 19598, 19627, 19629, 19754, 19781, 19783, 19944, 19968, and 19970.
- Bowell, E. (1992). [asteroid orbits]. *Minor Planet Circular* Nos. 19468, 19469, 19484, 19503, 19504, 19655, 19656, 19673, 19674, 19678, 19689-19691, 19818-19822, 19858, 19860, 19861, 19863, 19864, 19874, 19875, 19877, 19882, 19883, 19980, 19981, 19990, 20008, 20011-20014, 20016, 20018, 20024, 20025, 20027, 20037, and 20038.
- Buie, M. W., Bus, S. J., and Skiff, B. A. (1992). [asteroid photometry]. *IAU Circular* No. 5451.
- Bus, S. J. (1991). [asteroid identifications]. *Minor Planet Circular* Nos. 18105, 18107, 18108, 18111, 18113-18115, 18118, 18120, 18121, 18280, 18282, 18291, 18294, 18296, 18417, 18420, 18803, 18804, 18814, 18817, 18821, 19019, 19022, and 19025-19027.
- Bus, S. J. (1992). [asteroid observations]. *IAU Circular* No. 5279.

Bus, S. J. (1992). [asteroid identifications]. *Minor Planet Circular* Nos. 19664, 19826, 20009, 20010, 20012, 20016, 20017, 20019, and 20024--20026.

Faul, K. L. (1991). [asteroid identifications]. *Minor Planet Circular* Nos. 18105 and 18107.

Morrison, D., Bowell, E., Muinonen, K., and 22 additional authors. (1992). *The Spaceguard Survey: Report of the NASA International Near-Earth-Object Detection Workshop*. NASA, Washington, DC. Olmstead, C. M., and Skiff, B. A. (1992). [comet observations]. *Minor Planet Circular* Nos. 19726 and 19912.

Skiff, B. A. (1991). [asteroid identifications]. *Minor Planet Circular* Nos. 18117, 18428, 18812, and 19015.

Skiff, B. A. (1991). [asteroid and comet observations]. *Minor Planet Circular* Nos. 17488, 17491, 17683, and 17685.

Arecibo S-Band Radar Program

National Astronomy and Ionosphere Center
Space Sciences Building
Cornell University
Ithaca, NY 14853-6801

Donald B. Campbell

Strategy

The high-powered 12.6 cm wavelength radar on the 1000 ft. Arecibo reflector is utilized for a variety of studies of solar system bodies. These include: 1) The radar mapping of the surfaces of Mercury, Venus, the moon and Mars in both senses (usually the two circulars) of receive polarization; 2) high time resolution ranging measurements to Mercury and Mars to obtain height profiles and scattering parameters in the equatorial region and to test relativistic and gravitational theories; 3) measurements of the orbital parameters, scattering properties, figure and spin vectors of asteroids and comets; and 4) observations of the satellites of Mars, Phobos and Deimos, and the Galilean satellites of Jupiter.

Progress and Accomplishments

Application of newly developed techniques to allow delay-Doppler mapping of overspread targets resulted in the verification of an 'ice' cap at the north pole of Mercury and the discovery of a similar feature at the south pole. Radar properties of these features are similar to those of Mars' southern polar cap. Technique also allowed the first range measurement to Ganymede and Callisto providing confirmation of ~250 km longitude error in the Callisto 92ephemerides first determined from recent Arecibo Doppler measurements. Arecibo measurements of the polarization properties of the reflected signal from features on Venus are being combined with Magellan data to study the roughness properties of volcanic flows and the origin of the high reflectivity/low emissivity regions associated with Maxwell Montes and other elevated areas. The lunar imaging program achieved resolutions of <50m over several areas. Ranging measurements to the near-Earth asteroid 1991Jx, achieved a resolution of 0.2 fsec (30m) yielding a time delay estimate with a fractional precision of 5 parts in 109. Delay-Doppler imagery shows an irregular, non-convex shape for 1991Jx. All delay-Doppler asteroid radar astrometry data obtained between 1980 and 1990 has now been published.

Anticipated Accomplishments

Asteroid 4179 Toutatis will approach within 0.025 AU (10 lunar distances) of the Earth on December 8, 1992, providing a unique opportunity for very high resolution delay-Doppler imaging - probably the best opportunity for many years. Mars will be at opposition in late 1992 early 1993, providing opportunities for the study of areas of very high decimeter-scale surface roughness utilizing the new mapping techniques. Additional lunar observations will be made in August 1992 attempting to measure fine-scale lunar topography utilizing time-delayed interferometric techniques. Analysis of Venus polarization data will continue with emphasis on volcanic flow features in the southern hemisphere and areas of high reflectivity/low emissivity discovered in the Magellan data. In early 1993, construction work will commence on major modifications to the Arecibo antenna and S-Band radar system which will result in sensitivity improvements averaging about a factor of twenty over the current system.

Publications

"Asteroid 1986 DA: Radar Evidence for a Metallic Composition", S.J. Ostro, D.B. Campbell, J.F. Chandler, A.A. Hine, R.S. Hudson, K.D. Rosema, and I.I. Shapiro, *Science*, **252**, 1399, 1991.

"Geology and Structure of Beta Regio: Results from Arecibo Radar Imaging", D.A. Senske, J.W. Head, E.R. Stofan, and D.B. Campbell, *Geophys. Res. Lett.*, **18**, 1159, 1991.

"Geology and Tectonics of Beta Regio, Guinevere Planitia, Sedna Planitia, and Western Eistla Regio, Venus: Results From Arecibo Image Data", D.A. Senske, D.B. Campbell, E.R. Stofan, P.C. Fisher, J.W. Head, N.J.S. Stacy, J.C. Aubele, A.A. Hine, and J.K. Harmon, *Earth, Moon and Planets*, **55**, 163, 1991.

"Geology and Tectonics of the Themis Regio-Lavinia Planitia-Alpha Regio-Lada Terra Area, Venus: Results from Arecibo Image Data", D.A. Senske, D.B. Campbell, J.W. Head, P.C. Fisher, A.A. Hine, A. de Charon, S. Frank, S. Keddle, K. Roberts, E.R. Stofan, J. Aubele, L. Crumpler, and N.J.S. Stacy, *Earth, Moon and Planets*, **55**, 97, 1991.

"Asteroid Radar Astrometry", S.J. Ostro, D.B. Campbell, J.F. Chandler, I.I. Shapiro, A.A. Hine, R. Velez, R.F. Jurgens, K.D. Rosema, R. Winkler, and D.K. Yeomans, *Astron. J.*, **102**, 1490, 1991.

"Analysis of Volcanic Surface Morphology on Venus from Comparison of Arecibo, Magellan and Terrestrial Airborne Radar Data", B.A. Campbell and D.B. Campbell, submitted to *J. Geophys. Res.*, October 1991.

"Radar Detection of Centimeter-Sized Orbital Debris; Preliminary Arecibo Observations at 12.6 cm Wavelength", T.W. Thompson, R.M. Goldstein, D.B. Campbell, E.G. Stansbery, and A.E. Potter, *Geophys. Res. Letters*, **19**, 257, 1992.

"Mars Radar Mapping: Strong Backscatter from the Elysium Basin Outflow Channel", J.K. Harmon, M.P. Sulzer, P.J. Perillat, and J.F. Chandler, *Icarus*, **95**, 153, 1992.

"Interstellar Nomads: The Problem of Detecting Comets", E.M. Jones, W.I. Newman, and D.B. Campbell, *J. British Interplanetary Soc.*, in press, 1992.

"The Density Fluctuation Power Spectrum of the Inner Solar Wind", J.K. Harmon and W.A. Coles, Proceedings of the Seventh International Conference on the Solar Wind, *COSPAR Colloquia Vol. 3*, in press, 1992.

"Mars Radar Scattering: Arecibo/Goldstone Results at 12.6-cm and 3.5-cm Wavelengths", J.K. Harmon, M.A. Slade and R.S. Hudson, *Icarus*, in press, 1992.

Physical Observations of Comets: Their Composition, Origin, and Evolution

The University of Texas
McDonald Observatory

Anita L. Cochran

Strategy

Our goal is to study the composition, origins, and evolution of comets. The composition will be studied using spectroscopic observations of primarily brighter comets at moderate and high resolution to study the distribution of certain gasses in the coma. The origins will be addressed through an imaging search for the Kuiper belt of comets. The evolution will be addressed by searching for a link between comets and asteroids utilizing an imaging approach to search for a coma.

Progress and Accomplishments

During the past year, each of the three sub-topics of this program were addressed, with the most emphasis on the search for the Kuiper belt of comets.

We have now imaged 0.25 sq. degree of the sky to a limiting magnitude (V) of 24. The images were obtained near the plane of the ecliptic. In the past year we have developed extensive experience with obtaining, processing and analyzing such data. To date we have not detected any objects at the distance of the theorized Kuiper belt, although an asteroid with $m=20.3$ was discovered. The observations and the analysis have taken the bulk of the effort during the past year. Presentations on this program were presented at the Asteroids, Comets, Meteors 91 meeting in June 1991, the DPS meeting in November 1991, and the AAS meeting in January 1992.

We have had 2 spectroscopy observing runs during the past year. One of these runs concentrated on Pluto (as part of a different program) but included spectra of some faint comets. The other observing run was dedicated to time resolved spectroscopy of P/Schwassmann-Wachmann 1. Unfortunately, during this observing run, the comet had very low CO⁺ emission, which faded during the course of the observing run.

We have done extensive analysis of extant cometary spectroscopy during the past year, culminating in submission of two papers on a group of comets. One paper concentrates on the CN, CH, C₂, C₃, and NH₂ emissions, while the other paper concentrates on the dust. These papers include the model dependent results from the data. The complete set of fluxes and column densities are being archived in the NASA Planetary Data System Small Bodies Node database, where they may be accessed by any researcher with network capabilities.

We have begun a major study of the distribution of OH in the comae of comets in collaboration with David Schleicher of Lowell Observatory. The project will combine long-slit CCD spectra, aperture photometry, narrow-band imaging and IUE spectroscopy in order to determine the best photodissociation lifetimes.

As part of a Senior Thesis being supervised by Anita Cochran, Anthony Trout is using a vectorial model to analyze C2, C3, and CN profiles from comet Halley in order to determine if changes in the shape of the gas profiles can be explained by changes in the light-curve. Pre-perihelion lifetimes (when activity was very low) have been determined and these lifetimes along with changes in activity are being incorporated into the model to try to match the observed profiles.

We observed four Earth-approaching asteroids looking for evidence of a faint coma to indicate low level cometary activity. Despite some technical difficulties associated with this project, we can conclude that these four objects are essentially stellar.

Anticipated Accomplishments

During the next year, our emphasis will again be on the search for the Kuiper belt of comets. We expect that we will double our sky coverage. This will allow for significant analysis of the statistics.

We will again be obtaining long-slit spectra of comets, with emphasis on the OH distribution. Our study so far has shown that it is important to obtain OH profiles when the Sun is displaying lower activity levels than with the data we already have. The Sun will be between solar maximum and minimum during the next year. There are several potential targets whose heliocentric distances are favorable ($<2\text{au}$).

We intend to observe asteroid 4179 Toutatis during December 1992 when it makes its very close passage by the Earth. We will be looking to characterize this object and search for cometary emissions.

Publications

"Ultraviolet Spectroscopy of Comet Austin (1989)" (J. H. Valk, C. R. O'Dell, A. L. Cochran, W. D. Cochran, C. B. Opal and E. S. Barker) *Astrophys. J.*, **388**, 621-632, 1992.

"The McDonald Observatory Faint Comet Survey: Gas Production in 17 Comets" (A. L. Cochran, E. S. Barker, T. F. Ramseyer and A. D. Storrs) *Icarus*, in Press, 1992.

"Spectrophotometry of the Continuum in 18 Comets" (A. D. Storrs, A. L. Cochran and E. S. Barker), *Icarus*, submitted, 1992.

"The Enigmatic Object 2201 Oljato: Is it an Asteroid or an Evolved Comet" (L. A. McFadden, A. L. Cochran, E. S. Barker, D. P. Cruikshank, W. K. Hartmann, S. J. Ostro) *JGR-Planets*, submitted, 1992.

"Book review: Comets in the Post-Halley Era" (A. L. Cochran) *Icarus*, **96**, 149-150, 1992.

Radial Velocity Detection of Extra-Solar Planetary Systems

The University of Texas
McDonald Observatory

William D. Cochran

Strategy

The goal of this program is to detect planetary systems in orbit around other stars through the ultra-high precision measurement of the stellar radial velocity variations due to orbital motion of the star around the star-planet barycenter. Our survey of 33 nearby solar-type stars to detect Jovian-mass companions is the essential first step in understanding the overall problem of planet formation. The McDonald Observatory Planetary Search (MOPS) program will accumulate the necessary statistics to determine the frequency of planet formation as a function of stellar mass, age, and composition.

Progress and Accomplishments

We have continued regular monthly observing runs to monitor radial velocity variations in our target stars. All observations are made using the McDonald Observatory 2.7-m telescope and coude spectrograph. Starlight from the telescope passes through a permanently sealed temperature stabilized I2 gas absorption cell before the light enters the spectrograph. Relative radial velocity variations are then measured by determination of the Doppler shift of the stellar photospheric lines with respect to the stabilized I2 reference lines. The I2 cell thus provides a stable metric for these high-precision measurements. Our observations of a standard spot on the lunar surface over the past two years show an rms dispersion of individual measurements from the mean of 6.4 m/s. This demonstrates that both the random and systematic errors are well under control, and that we have achieved the measurement precision necessary to detect Jovian planets around solar-type stars. In the survey itself, we now have a sufficient time baseline to see some clear trends in many stars. There are several stars which are showing virtually constant radial velocities for the four years of the survey. These stars show essentially no slope in their radial velocities, and we can rule out the presence of planets more massive than Jupiter with periods less than 15 years in these cases. We have several other stars which show statistically significant slopes to their radial velocities. In many cases, the magnitude of the slope indicates the possibility of a planetary-mass companion to these stars. In other cases, the slope is clearly due to a more massive (i.e. stellar) companion. In addition, there are some stars (primarily F5-F8 dwarfs) which show radial velocity variability due to short-period low-amplitude stellar pulsations.

Anticipated Accomplishments

We will continue regular observations of the 33 stars on the MOPS list. We will carefully monitor the stellar photospheric line profile shapes of those stars which have possible low-mass companions. This will reveal whether the observed radial velocity variability is indeed due to orbital motion or is the result of intrinsic stellar photospheric or magnetic activity cycle variability. We intend to obtain concentrated time-series observations on selected stars which show possibly periodic short-term radial velocity variations. These variations are possibly due to intrinsic pulsation modes of the star. We need to fully understand the intrinsic stellar variability in order to sort out extrinsic (orbital) from intrinsic (pulsational) radial velocity variations.

Publications

Cochran, W. D., A.P. Hatzes, and T. J. Hancock (1991). Constraints on the Companion Object to HD114762. *Ap. J. (Letters)* **380**, L35-L39.

Cochran W. D. and A. P. Hatzes (1991). A Radial Velocity Search for Extra-Solar Planetary Systems. *Bull. Amer. Astron. Soc.* **23**, 1234.

Cochran W. D. and A. P. Hatzes (1991). A High-Precision Radial Velocity Survey for Other Planetary Systems. *Bull. Amer. Astron. Soc.* **23**, 1314.

Hatzes, A. P. and W. D. Cochran (1991). Precision Radial Velocities of K Giants. *Bull. Amer. Astron. Soc.* **23**, 903.

Noh, H.-R., E. T. Vishniac, and W. D. Cochran (1991). Gravitational Instabilities in a Protoplanetary Disk. *Ap. J.* **383**, 372-379.

Noh, H.-R., E. T. Vishniac, and W. D. Cochran (1991). Gravitational Instabilities in a Protoplanetary Disk Including the Effects of Magnetic Fields. *Ap. J.* in press.

Noh, H.-R., E. T. Vishniac, and W. D. Cochran (1992). An Examination of the $m=1$ Instability in a Low Mass Protoplanetary Disk. *Ap. J.* submitted.

Volatiles in the Outer Solar System

NASA Ames Research Center
Moffett Field, CA 94035

Dale P. Cruikshank

Strategy

This program is an investigation into the composition of the bodies of the outer Solar System, particularly the satellites of the planets, Pluto, asteroids, and comets. While the primary focus is on ices on the surfaces of these bodies, the investigation includes the detection and study of organic solids and minerals, with emphasis on the origin of certain classes of meteorites. The study of ices includes considerations of the interaction of the surface materials with atmospheres (in the cases of Titan, Triton and Pluto). This work is accomplished primarily through astronomical observations of target bodies with large telescopes and associated infrared spectroscopic, photometric, and radiometric instruments. Some of this work is in direct support of NASA flight programs to the outer parts of the Solar System.

Progress and Accomplishments

Recent progress includes the discovery of the basaltic composition of three Earth-approaching asteroids, each having close similarity to the surface of Vesta, which is known to be a differentiated asteroid with a basaltic surface. The three small asteroids may be parts of a single object that is also the source of some or all of the eucrite, diogenite, and howardite meteorites. In addition, a spectral feature attributed to triple-bonded CN was identified in two comets, three asteroids, the rings of Uranus, and the dark hemisphere of Iapetus. These bodies all share a low albedo and red color, yet represent four kinds of diverse objects. The occurrence of organic solids on these outer Solar System bodies may establish a link with interstellar material. It also appears to demonstrate the lack of alteration of these surfaces by water, since water tends to destroy the CN bond. Further, this work included the identification of the mineralogy of the Galileo target asteroid, 951 Gaspra, in advance of the encounter of October 1991. Data acquired in this investigation showed an absorption band near 1 micrometer attributed to olivine and pyroxene, and weak second pyroxene band centered near 2.0 micrometers. This mineral signature plus the overall redness of the spectrum suggest that Gaspra originated in the lower mantle of a differentiated parent body. In addition, this investigation resulted in the discovery of carbon monoxide and carbon dioxide ices on the surface of Neptune's satellite Triton through infrared spectroscopy with a large telescope. These two molecules were not detected by Voyager during its 1989 encounter. Both molecules are of great importance in determining the nature of the surface-atmosphere interaction, the chemistry of the atmosphere, and the chemistry of the sub-nebula from which Triton condensed.

Publications

Baines, K. H., R. H. Brown, D. L. Matson, R. M. Nelson, B. J. Buratti, J. P. Bibring, Y. Langevin, C. Sotin, A. Carusi, A. Coradini, R. N. Clark, M. Combes, P. Drossart, B. Sicardy, D. P. Cruikshank, V. Formisano, R. Jaumann (1991). VIMS/Cassini at Titan: Scientific objectives and observational scenarios. *ESA SP XXX*, 1-5.

Cruikshank, D. P., L. J. Allamandola, W. K. Hartmann, D. J. Tholen, R. H. Brown, C. N. Matthews, and J. F. Bell (1991). Solid CN bearing material on outer solar system bodies. *Icarus* **94**, 345-353.

Cruikshank, D. P., D. J. Tholen, W. K. Hartmann, J. F. Bell, and R. H. Brown (1991). Three basaltic Earth-crossing asteroids and the source of the basaltic meteorites. *Icarus* **89**, 1-13.

Cruikshank, D. P. (1991). A bright future for planetary astronomy? *Sky and Telescope*, January, p.4.

Goldader, J. D., D. J. Tholen, D. P. Cruikshank, and W. K. Hartmann (1991). Galileo support observations of asteroid 951 Gaspra. *Astronomical Journal* **102**, 1503-1509.

***Stellar Occultations in the 1990's:
Portable, High-Speed, CCD Photometers***

NASA Ames Research Center, Code SSA

Edward W. Dunham

Strategy

The structure of planetary atmospheres and rings may be deduced by observation of occultations of stars by planets. (A stellar occultation occurs when a planet passes between an observer and a star.) The resulting data are analyzed to provide high-resolution vertical atmospheric temperature profiles, or high-resolution optical depth profiles through a planetary ring system. Precise knowledge of both the timescale of the observed light-curve and the observer's position are required. Since occultations occur with equal probability all over the Earth, portable observing systems are also required. Four such systems are being built as part of a collaboration with workers at the University of Arizona, Lowell Observatory, and MIT.

Progress and Accomplishments

None - this is a new project.

Anticipated Accomplishments

The system design and construction will be complete by the end of calendar 1992, and observations of two occultations involving Pluto will be attempted in the first two months of 1993.

The Atmospheres of Pluto and Triton: Occultation Studies

Department of Earth, Atmospheric, and Planetary Sciences
Massachusetts Institute of Technology
Cambridge, MA 02139

James L. Elliot

Strategy

We are investigating the atmospheres of Triton and Pluto for three reasons: (i) since these bodies are the products of processes 30-50 AU from the sun, their study will further our understanding of the processes of formation and evolution of the outer solar system, (ii) the atmospheres of Pluto-Charon and Triton exhibit several unique physical processes, the understanding of which will further our general understanding of planetary atmospheres, and (iii) the more we know about the atmospheres of Pluto and Triton from ground-based observations, the more effectively we can plan future space-based investigations. Stellar occultations observed from Earth yield temperature-pressure profiles over several scale heights, with a spatial resolution of a few kilometers. With this technique, we can sample the atmospheric structure throughout diurnal and seasonal cycles, at the times of suitable occultation events (on average, about once per year for Triton, and once every four years for Pluto).

Progress and Accomplishments

Our accomplishments during the past year include (i) testing the isothermal prediction of the "methane-thermostat" model by re-analyzing our KAO occultation data for Pluto's atmosphere—we found that Pluto's upper atmosphere is isothermal to a limit of 0.1 K km^{-1} ; (ii) completion of the CCD strip scans needed to extend our search for Pluto occultation candidates through the end of the century (iii) obtaining the CCD strip scans needed for the Triton candidate search for 1992-2000; (iv) continuing the collaboration with our colleagues at Lowell Observatory to use all available data from the 1988 occultation to determine accurate radii for several levels of Pluto's atmosphere; (v) obtaining multi-color photometry of Pluto occultation candidates that will be used for establishing the best potential occultations; (vi) compiling a list of candidate stars for Triton occultations, with finder charts and visibility zones; (vii) refining the prediction for the occultation of P17 by Pluto, which, unfortunately, will unlikely be visible from Earth; and (viii) observation of four appulses by Pluto at the IRTF with ProtoCAM, from which we have begun to generate a resolved light-curves for Pluto and Charon. Our first conclusion from the latter work is that Charon is variable at $2.2 \text{ }\mu\text{m}$.

Anticipated Accomplishments

The results of (i), (iii), (v), (vi), and (viii) have been published (see below), and we are currently drafting a manuscript for the results of (iv). We shall work with our colleagues at Lowell Observatory to compare the predictions of the P17 occultation obtained with photographic plates, the Carlsberg Automatic Meridian Circle, and CCD's in order to evaluate which of these techniques is the most reliable for refining predictions for Pluto and Triton occultations. Also, we shall extend our candidate lists for Pluto and Triton to the latter half of the decade. Observation of the occultation of P20 by Pluto will be attempted from Australia if final predictions indicate that this occultation might be observable. Simultaneous observations of this event at optical and infrared wavelengths can be used to determine whether Pluto has a haze layer in its atmosphere.

Publications

Bosh, A. S., L. A. Young, J. L. Elliot, H. B. Hammel, and R. L. Baron 1992. Photometric Variability of Charon at 2.2 μm . *Icarus* **95**, 319-324.

Elliot, J. L., and L. A. Young 1992. Analysis of stellar occultation data for planetary atmospheres. I. Model fitting, with application to Pluto. *Astron. J.* **103**, 991-1015.

McDonald, S. W., and J. L. Elliot 1992. Triton Stellar Occultation Candidates: 1992-1994. *Astron. J.* (submitted).

Sybert, C. B., A. S. Bosh, L. M. Sauter, J. L. Elliot, and L. H. Wasserman 1992. Magnitudes of selected stellar occultation candidates for Pluto and other planets, with new predictions for Mars and Jupiter. *Astron. J.* **103**, 1395-1398.

Planetary Spectroscopy

Lunar and Planetary Laboratory
University of Arizona
Tucson Az 85721

Uwe Fink

Strategy

Our effort is divided into instrumentation and observational research. In the area of instrumentation our primary objective is the maintenance and slow improvement of our CCD camera and data acquisition system for continuing use of any interested LPL user. The main goal of our observational research is CCD spectroscopic and imaging studies of the solar system in support of spacecraft investigations. Our studies include the physical behavior of comets, the atmospheres of the gaseous planets, and the solid surfaces of satellites and asteroids.

Accomplishments

During the past year we have continued the analysis of our P/Halley data set by completing a paper on the spatial distribution and scale lengths of C_2 , CN NH_2 and OI. We found that good scale lengths could be extracted from the pre-perihelion data but the post-perihelion observations were strongly affected by P/Halley's time-varying production rate. The results were published in *Ap. J.* **383**, 356 (1991). Further analysis, presented at the Flagstaff ACM conference showed that the post-perihelion spatial emission profiles could be fitted well using our scale lengths and a time-varying production rate commensurate with P/Halley's light-curve.

We also continued our work on the composition and microstructure of the surface of Triton. We measured a set of absorption coefficients of the 2.15 μ collision induced band of liquid nitrogen. By extrapolating our values to the solid phase at a temperature of 38°K and applying a Hapke scattering model we were able to constrain the N_2 grain diameters (or more correctly the size of scattering centers) to the order of 1-2 cm (*Icarus*, **93**, 169, 1991). In addition we carried out improved observations of Triton's albedo spectrum between 5200 and 10,000°. A Hapke scattering model applied to this data has led us to believe that methane ice is widely distributed on Triton's southern hemisphere. If CH_4 condenses as separate particles the mean grain size of CH_4 is of the order of 100 fm. If CH_4 condenses together with N_2 then the mixing ratio of CH_4 in solid N_2 of the surface must be considerably higher than it is in Triton's atmosphere (*Icarus*, **93**, 379, 1991).

Other analyses carried out during this funding period was the confirmation of the weak absorption feature in Io's spectrum at 2.125 μ and measurements of its

position, integrated absorption, half-width and peak absorption coefficients (*Icarus*, **95**, **325**, 1992). This analysis was performed on a spectrum of Io taken in 1976 with the KPNO 4 m telescope.

In collaboration with R.L. Marcialis we participated in a summary paper on the wavelength dependence of the albedo of Pluto and Charon (*Astron. J.*, **103**, **1389**, 1992). A joint project with Steve Tegler and Susan Wyckoff on narrow band NH_2 imaging of comet P/Brorsen-Metcalf was also completed (*Ap. J.*, **384**, **292**, 1992). The NH_2 daughter distribution showed good agreement with an NH_3 parent origin.

Anticipated Accomplishments

For the coming proposal year we wish to continue our monitoring of the chemical composition of a sample population of comets. As part of this program we have observed a very odd comet: Yanaka (1988). This comet showed the usual emissions by OI and NH_2 but displayed no hint of any C_2 or CN emissions. A preliminary report of this was given at the 1991 Palo Alto DPS meeting. We are now working on a production rate analysis and plan to submit this paper for publication as soon as possible. We are also planning to complete our analysis of the spatial distribution of the continuum and the emission species C_2 , CN, NH_2 , and OI using a time-varying production rate.

In January 1991 Dr. Martin Hoffmann from the University of Bonn joined us for a year to carry out light-curve investigations of high inclination asteroids. In conjunction with this effort we are pleased to report a very unusual reflection spectrum of the recently discovered asteroid 1992 AD (5145) which we observed 1992 Feb.01.23. The asteroid exhibited the steepest red spectrum of any known solar system object from 0.50 to 1.0 μm . This steep red slope is difficult to match with conventional silicate or meteoritic materials and probably requires a mixture of organic residues or "tholins" to explain its reflectivity spectrum. We are currently working on writing this data up and getting it published.

Submillimeter Wave Planetary Observation Development

Jet Propulsion Laboratory
4800 Oak Grove Dr.
Pasadena, CA 91109

Dr. Margaret A. Frerking, JPL
Co-investigators: Dr. William R. McGrath,
Dr. Samuel Gulkis, JPL

Strategy

The objective of this task is to build a cryogenically cooled 620 - 700 GHz receiver using superconducting mixers for the Caltech Submillimeter Observatory (CSO) on Mauna Kea. The receiver will have applications for very high spectral resolution spectroscopy to investigate emission from chemical species in planetary atmospheres, satellite atmospheres, and comets.

Progress and Accomplishments

During the last year we have conducted laboratory receiver tests with both Nb and NbN superconductor-insulator-superconductor (SIS) tunnel junction mixers and fabricated all the receiver components that will be needed at the CSO. Full end-to-end receiver tests will begin once the assembly of the components in the dewar is complete. The initial frequency of operation is at 626 GHz, that of the J=1-0 transition of HCl.

NbN and Nb junctions with integrated tuning elements were designed and fabricated. An important step was the development of submicron area NbN mesa junctions using E-beam lithography. We have extensively investigated with DC measurements the small area (0.17 μm^2) NbN tunnel junctions. More than 150 I-V curves of junctions from four different batches have been studied in order to distinguish between shorts, open-circuits, ohmic contacts, weak links, and good tunnel junctions.

The best results have been obtained with the Nb junctions. Using a single open-circuited microstrip tuning element, a mixer noise $T_m = 3000$ K was obtained. In order to broaden the bandwidth and perhaps lower the RF losses, a two-section short-circuited microstrip tuning element was tested. A mixer noise $T_m = 2000$ K was achieved. This performance is the best reported to date at this frequency and meets the initial science needs. Future improvements by a factor of two to three are expected as the SIS tunnel junction quality improves.

Anticipated Accomplishments

During the coming year we plan to install the receiver on the CSO and make it available for use by the community (this is currently scheduled for December 92), improve the performance of the receiver at 626 GHz as the SIS tunnel junction quality improves, and upgrade the IF system for better performance.

Publications

H. H. S. Javadi, W. R. McGrath, S. R. Cypher, B. Bumble, B. D. Hunt, and H. G. LeDuc, "Performance of SIS Mixers at 205 GHz Employing Submicron Nb and NbN Tunnel Junctions," Digest of the 15th International Conference on Infrared and Millimeter Waves, p. 245, Orlando, FL (1990).

W. R. McGrath, J. A. Stern, H. H. S. Javadi, S. R. Cypher, B. D. Hunt, and H. G. LeDuc, "Performance of NbN Superconductive Tunnel Junctions as SIS Mixers at 205 GHz," IEEE Trans. on Magnetics 27, 2650 (1991).

W. R. McGrath, J. A. Stern, and H. G. LeDuc, "Performance of All-NbN Superconductive Tunnel Junctions as Mixers at 205 GHz," Physica B 165 & 166, 75 (1990).

K. Jacobs, and W. R. McGrath, "Large Scale Modeling of a Submillimeter Wave SIS Mixer with Integrated Tuning Elements," Digest of the 14th International Conference on Infrared and Millimeter Waves (M. von Ortenberg, ed.), p. 539, Wurzburg, Germany (1989).

W. R. McGrath, K. Jacobs, J. Stern, H. G. LeDuc, R. E. Miller, and M. A. Frerking, "Development of a 600-700 GHz SIS Receiver," Digest of the 1st International Symposium on Space Terahertz Technology, p. 409, Ann Arbor, MI (1990).

Javadi, H. H. S., McGrath, W. R., LeDuc, H. G., Bumble, B., "Onset of Dispersion in Niobium Transmission Lines," accepted for publication in Applied Physics Letters (1992).

Surveying the Solar System

Lunar and Planetary Laboratory and Steward Observatory
The University of Arizona
Tucson, Arizona 85721

Tom Gehrels

Strategy

Some populations of objects in the solar system are poorly known, and the long-range goal of this program is to improve that situation. For instance, we are working with Drs. C. J. and I. van Houten of the Leiden Observatory in a continuation of the Palomar-Leiden Survey to investigate the statistics of Trojan asteroids. We are also developing new techniques of sky surveillance by scanning with a CCD, particularly for the discovery of near-Earth objects. Our recent discoveries of Trojans and near-Earth objects are being analyzed in terms of magnitude-frequency relations.

Progress and Accomplishments

We are observing full time, during the half of each month centered on New Moon, with the Spacewatch Telescope which is the 91-cm Newtonian reflector of the Steward Observatory on Kitt Peak, equipped with a 2048 x 2048 Tektronix CCD and a Solbourne work station. Spacewatch is finding more than 2,000 main-belt asteroids and nearly two near-Earth objects per month; only the latter are followed with astrometry. The largest of the near-Earth objects are discovered, sometimes at great distance from the Earth. Asteroid 5145 has a diameter of 140-km; its orbit ranges approximately between the orbits of Saturn and Neptune. We also discover the smallest of objects with sizes in the range 10 to 100 m; a preliminary analysis of their statistics indicates that there is an excess by as much as a factor of 100 over the power-law extrapolation from our findings of the larger ones.

Projected Accomplishments

The discovery of near-Earth asteroids is to be further improved in hardware, software, and operation. We expect to publish soon the first magnitude-frequency relation obtained directly from observations of the near-Earth objects.

Publications

van Houten, C. J., van Houten Groeneveld, I., Wisse-Schouten, M., Bardwell, C., Green, D.W.E., and Gehrels, T. (1991). The Second Palomar-Leiden Trojan Survey. *Icarus*, **91**, 326-333.

Rabinowitz, D. L. (1991). Detection of Earth-approaching Asteroids in Near Real-Time. *Astron. J.*, **101**, 1518-1559.

Gehrels, T. (1991). Scanning with Charge-Coupled Devices. *Space Science Reviews* **58**, 347-375.

Scotti, J. V., Rabinowitz, D. L., and Marsden, B. G.
(1991). Near Miss of the Earth by a Small Asteroid.
Nature, **354**, 287-289.

1991 Io Occultations: Observing and Data Analysis

Jet Propulsion Laboratory
MS 183-501
Pasadena, CA 91109

Jay D. Goguen

Strategy

Having successfully acquired an extensive, high-quality data set of IR observations of the rare 1991 series of occultations of Io by Europa, we propose to analyze the data to map the thermal radiation from Io's volcanoes at 10 km spatial resolution. These maps will be used to distinguish between hot spot physical models, to yield precise measurements of the latitude, longitude, area, and temperature of each active eruption occulted, and to improve estimates of Io's global heat flow. Multiple occultations of Loki (and Pele) will be combined to reconstruct high resolution thermal emission images of the eruptions by employing tomographic techniques. The goal is to develop an overall picture of Io's observable volcanic phenomena that will serve as a post-Voyager and pre-Galileo basis for hot spot modelling efforts and Galileo mission planning.

Progress and Accomplishments

Much of the work in FY92 has focussed on refining the satellite ephemerides to match the observed light-curves. The initial analysis showed that there was a 300 km discrepancy between the best predicted relative positions of Io and Europa and those needed to match the actual relative positions as measured using the occultation light-curves. More precise ephemerides are needed to reconstruct images from the individual hot spot occultations obtained on different dates. Toward this end, a revised set of parameters for J. Lieske's Galsat model of the satellite orbits has been determined. The predictions of this revised orbital model will be made available to the other occultation observers so that all of the occultation data will be analyzed using the same ephemerides.

Anticipated Accomplishments

We propose to analyze this extensive data set to derive the most detailed picture of Io's volcanic thermal emission to date. Analysis of each occultation light-curve yields the diameter, latitude and longitude of the hot spot and the brightness temperature at that wavelength. By combining multiple wavelength data, the areal distribution of physical temperatures is constrained. Temporal variation is found from occultations of the same hot spot on different dates. Io's heat flow is determined by the combination of the hot spot location and thermal structure data. Physical models of hot spots will be discriminated by their thermal structure. Images of the hot spots at

3.8 and 10 micrometers will be reconstructed from multiple occultations. These results will give a picture of Io's thermal emission at spatial resolutions of about 10 km, more than an order of magnitude improvement over the previous best ground based images and comparable to that possible from the Galileo NIMS instrument.

Publications

Goguen, J. D., and W. M. Sinton (1985), Characterization of Io's Volcanic Activity by Infrared Polarimetry, *Science* **230**, 65-69;

Goguen, J. D. et al (1988), Io Hot Spots: IR Photometry of Satellite Occultations, *Icarus* **76**, 465-484;

Hillier, J. P., et al. (1990), Voyager Disk-Integrated Photometry of Triton, *Science* **250**, 419-421;

Spencer, J. R., et al. (1990), Discovery of Hot Spots on Io using Disk-resolved Infrared imaging, *Nature* **348**, 618-621;

Brown, R. H., et al. (1991), MS 183-501, Triton's Global Heat Budget, *Science* **251**, 1465-1467.

Planetary Submillimeter Astronomy

Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109

Samuel Gulkis

Strategy

The goal of this task is to study the composition and distribution of molecules in the atmospheres of the planets and satellites in order to understand the origin and evolution of planetary atmospheres, isotopic abundance ratios in the primordial nebula, and ongoing physical processes.

Progress and Accomplishments

In the previous year, we observed HDO in the atmosphere of Venus and estimated the vertical distribution of water. We continued our studies of the stability and global distribution of Io's atmosphere based on millimeter observations of SO₂. New upper limits on atmospheric H₂S, SO, and CO were obtained.

Anticipated Accomplishments

This year we plan to continue our studies of SO₂ on Io and to search for HCN and PH₃ on Jupiter. A new 620 GHz SIS receiver will be installed on the Caltech Submillimeter Telescope and initial observations of Venus will begin.

Publications

Lellouch, Emmanuel, Belton, Michael, de Pater, Imke, Gulkis, Samuel & Encrenaz, Terese, "Io's atmosphere from microwave detection of SO₂", *Nature*, 346, No. 6285, pp. 639-641, August 16, 1990.

Encrenaz, T., Gulkis, S., and E. Lellouch, "Heterodyne Spectroscopy of Planetary and Satellite Atmospheres in the Millimeter and Submillimeter Range", in *Coherent Detection at Millimeter Wavelengths and Their Application*, Ed. Encrenaz, Laurent, Gulkis, Kolberg, and Winnesser. *Nova Science Publishers*, pp425-453(1991).

Wannier, P.G., Pagani, L., Kuiper, T.B.H., Frerking, M.A., Gulkis, S., Encrenaz, P., Pickett, H.M., Lecacheux, A., and Wilson, W.J., "Water in Dense Molecular Clouds", *The Astrophysical Journal*, 377, 171-186, Aug. 10, 1991.

Gulkis, S., "Rotation of Solar System Bodies: Jupiter, Saturn, Uranus, and Neptune", *Highlights in Astronomy*, Vol. 9, 1992.

Gulkis, S., and Imke dePater "Radio Astronomy, Planetary," in *Encyclopedia of Physical Science and Technology*, Vol. 14, R.A. Meyers, Ed., (In Press -1992).

Gulkis, S., and M. J. Janssen, Properties of the Deep Atmospheres of the Planets from Radio Astronomical Observations, *Microwave Remote Sensing*, M. J. Janssen, Ed. (in Press 1992).

Lellouch, E., Belton, M., depater, Imke, Paubert, G., Gulkis, S., and Encrenaz, Th., "The Structure, Stability, and Global Distribution of Io's Atmosphere", submitted to *Icarus* 1992.

Encrenaz, T., Lellouch, E., Paubert, G., and Gulkis, S., "First Detection of HDO in the Atmosphere of Venus at radio wavelengths: an estimate of the H₂O vertical distribution", *Astron. Astrophys.* 246, L63-L66(1991)

Infrared Observations of Cometary Dust

Jet Propulsion Laboratory
Pasadena, CA 91109

Martha S. Hanner

Strategy

Infrared spectroscopy and photometry are employed to study the composition of cometary dust and its relationship to interstellar dust, using the NASA Infrared Telescope Facility and other telescopes as appropriate. 2-13 μm spectra are being acquired for a sample of new and evolved comets, over a wide range in r , to study the structure of the 8-13 μm silicate feature, search for hydrocarbon features and for icy grains. The IHW archive and the PI's ir data base are used to study the dust properties in Comet Halley and other comets.

Progress and Accomplishments

- i) Comet P/Faye was observed at the IRTF at $r = 1.59$ AU. Broad, weak silicate emission is present, the first such spectral detection in a short-period comet.
- ii) Papers on the 7-13 μm spectra of comets P/Brorsen - Metcalf, Levy (1990 XX) and Austin (1990 V) were written.
- iii) The near - ir light-curve of Comet Halley was constructed and analyzed; paper is in preparation.

Anticipated Accomplishments

- i) Conduct 2 observing runs at the IRTF to acquire 2-13 μm spectra of comets and YSOs, including Comet P/Schaumasse.
- ii) Analyze Halley thermal emission data and combine with JHK data to study temporal variations in dust optical properties.
- iii) Begin correlative study of dust properties from infrared data on > 25 comets.

Publications

Hanner, M. S., Veeder, G. J., Tokunaga, A. T. (1992). The Dust Coma of P/Giacobini-Zinner in the Infrared. *Astron. J.*, in press.

Lynch, D. K., Hanner, M. S. and Russell, R. W. (1992). 8-13 μm Spectroscopy and IR Photometry of

Comet P/Brorsen-Metcalf (1989) Near Perihelion. *Icarus*, in press.

Hanner, M. S. and A. T. Tokunaga (1991). Infrared Techniques for Comet Observations. In *Comets in the Post-Halley Era*, (ed. R. L. Newburn, M. Neugebauer, and J. Rahe), p. 67.

Hanner, M. S. (1991). The Infrared Zodiacal Light. In *Origin and Evolution of Dust in the Solar System*, (ed. A.C. Levasseur-Regourd), Kluwer, p. 171.

Grün, E., H. Fechtig, M. S. Hanner, J. Kissel, B.-A. Lindblad, D. Linkert, G. Morfill, and H. A. Zook (1991). In-Situ Exploration of Dust in the Solar System and Initial Results from the Galileo Dust Detector. In *Origin and Evolution of Dust in the Solar System*, (ed. A. C. Levasseur-Regourd), Kluwer, p. 21.

Asteroid Photometry

Jet Propulsion Laboratory
4800 Oak Grove Dr.
Pasadena, CA 91109

Alan W. Harris

Strategy

Photoelectric light-curves provide fundamental information about asteroids: rotation periods, pole orientations, shapes, and phase relations, which yield some information about the surface physical properties. This task is to carry on a program of such observations to increase the overall data base, obtain data on newly discovered asteroids, and to observe asteroids which are the subject of other complementary observations, such as occultations, radar, and IR.

Progress and Accomplishments

To date, approximately 1/3 of all known asteroid rotation periods and about 1/2 of all precision phase relations derive from TMO observations. Notable highlights of the last year include publication of results for 59 asteroids observed from 1979 to 1981, including 15 new or significantly improved rotation periods and precision phase curves for 28 objects. One light-curve taken in 1982 of the asteroid 952 Gaspra proved to be crucial to the determination of the shape and spin orientation of that object before the Galileo encounter. Precision phase relations of dark, moderate, and high albedo asteroids have been obtained which will lead the way to producing the next generation phase relation model for asteroids. A separate, but related activity has been to participate in studies of the possibility of near-Earth asteroid impact on the Earth, and efforts to increase discovery rates of this class of objects.

Anticipated Accomplishments

- i) Recent availability of CCD detectors for smaller telescopes and an increased interest within NASA on Near-Earth Asteroids (NEAs) motivate a shift in emphasis in my research. I plan to implement a program of CCD photometry of newly discovered NEAs with the goal of following up most new discoveries to obtain absolute brightness, light-curve, and at least some colorimetry. Presently only about 10-20% of new discoveries are followed up with any physical observations.
- ii) Conventional photometric observations and reductions will continue, with the highlight of the next year being a major campaign of observations of 4179 Toutatis.
- iii) Work will begin on a new three-parameter photometric model to fit the much larger and more precise set of phase relation data now available.

Publications

Ahrens, T.J. and A.W. Harris (1992) Near Earth asteroid orbit perturbation and fragmentation. Subm. to Nature.

Harris, A.W. (1991) Rotational motion of Asteroids. In Reports on Astronomy XXIA (D. McNally, ed.), Dordrecht: Kluwer pp. ____.

Harris, A.W., J.W. Young, T. Dockweiler, J.B. Gibson, M. Poutanen, and E. Bowell (1992). Asteroid Light-curve observations from 1981. *Icarus* 95, 115-147.

Magnusson, P. et al. (1992) Asteroid 951 Gaspra: Pre-Galileo physical model. *Icarus*, in press.

Palomar Planet-Crossing Asteroid Survey (PCAS)

Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, California 91109

Eleanor F. Helin

Strategy

The objective of this program is the discovery and follow-up of planet-crossing asteroids, related inner-belt asteroids and comets. The primary program is carried out with the 0.46 m Schmidt telescope at Palomar Observatory. The results, subsequent observations, and analysis provide insight into their populations, orbits, origins, physical characteristics (composition, size, shape), potential for impact, relationships to comets and meteorites, and for future spacecraft mission candidates.

Accomplishments

Sky coverage of 53,000 sq. degrees has led to the discovery of 17 Near-Earth Asteroids (NEAs), 2 Atens, 8 Apollos and 7 Amors, in the last 14 months, an unprecedented number of discoveries in such a short period. This high discovery rate reflects still greater sky coverage, improvement in focus and threshold detection. In addition, 275 other asteroids of all classes were discovered, reported and given designations including 45 high inclination asteroids (24 Hungarias and 21 Phocaeas). Although we continue to discover bright NEAs, we have found 6 small NEAs with absolute magnitude 19 or higher. This indicates a greater sampling of the smaller sized objects in the NEA population. 28 asteroids have been permanently numbered and another 14 previously numbered have been officially named. Of the newly numbered, four are NEAs. The most accessible asteroid, 1991 JW was discovered in May 1991. With its Earth-like orbit, it's observable for extended periods of time, allowing excellent opportunities for acquiring physical observations. 1991 JW appears to be a somewhat better mission candidate than (4660) Nereus, another PCAS discovery. Several excellent candidates with low delta V were discovered for future spacecraft missions. Another exciting object, 1984 QY1, recently found on old films, has an extremely eccentric orbit which travels inside the orbit of Mercury to approaching the orbit of Saturn. As co-investigator of target of opportunity under the "Exceptional Solar System Object", the Hubble Space Telescope successfully imaged the unusual object 1992 AD on 27 April.

In addition, PCAS discovered three new parabolic comets in the past 14 months. Two of these comets are distant, 1991r and 1992a, making their closest approach to the Sun at a distance of 4.85 A.U. and 3.01 A.U. respectively. Rarely are comets discovered with small telescopes at these large distances.

PCAS' rate of discovery in 1991/1992 continues to yield a dozen or more NEAs per year.

Anticipated Accomplishments

Continuing progress is anticipated in the automated identification and measurement procedures. Plans are in progress to upgrade to a CCD array to be retrofitted on the 0.46 m Schmidt. Our major thrust will be the conversion to a CCD camera system as promptly as possible.

Publications

Abstracts: Helin, E.F. (1991) "Near-Earth Asteroid Discovery Rate Review, in *Asteroid, Comets, and Meteors*, 1991" Proc.;

Helin, E.F. (1991) "International Conference on Near-Earth Asteroids and Near-Earth Objects Workshop Report", *IAU GA*, Argentina;

Helin, E.F. (1991) "The Palomar Planet-Crossing Asteroid Survey (PCAS) Discoveries: The Last Three Years", *AAS, DPS*.

Other: Discoveries and observed positions in 40 International Astronomical Union Circulars and 420 Minor Planet Circulars

Infrared Speckle Interferometry and Spectroscopy of Io

Physics & Astronomy Department
University of Wyoming

Robert R. Howell

Strategy

The principal goals of this project are to use a variety of high angular resolution techniques to study the nature of the volcanic activity on Jupiter's moon Io, and to use these techniques to study the regions surrounding young stars, where planetary system formation may be occurring.

Progress and Accomplishments

During the past year we have continued the Io infrared monitoring program, proceeded with the analysis of the 1991 Galilean satellite mutual event data, and obtained additional lunar occultation observations of young stars. A special effort was made to observe Io during February as Ulysses went through the Jupiter system. The emission from Loki (at a wavelength of 5 microns) has, for the period Dec. 91 through March 92, been at the lowest level we have seen during the several years of monitoring.

Our analysis of the mutual events forces us to conclude that there is a significant error in the current Galilean satellite ephemeris -- a conclusion also reached by the other observing groups. The predicted relative position of Io and Europa are in error by approximately 300 km. This unexpectedly large discrepancy has important implications for the interpretation of the mutual event data and for Galileo planning, and may also be important in studying the time evolution of the satellite orbits. The initial analysis of the mutual event data is straightforward, and as reported earlier, indicates activity as Loki and Pele. However, the detailed analysis which can provide precise positions for the hot spots and two-dimensional "images" of the Loki temperature distribution requires an accurate ephemeris. We have temporarily delay publication of the mutual event results, pending efforts at JPL to correct the ephemeris. If the ephemeris issue can't be resolved in the very near future, then we will proceed with publication of the initial analysis of the data, and will present a more detailed analysis when the ephemeris is understood.

We also obtained lunar occultation observations of several young stars. These most recently observed sources appear to be unresolved, unlike DG Tau, where we detected material within 10 AU of the star.

Anticipated Accomplishments

Our plans for the next year include completion of the mutual event analysis, and publication of the Io rotational light-curves which we have obtained over the past several years. These light-curves provide a simply way to summarize the changing activity. We are also placing increased emphasis on obtaining infrared data simultaneously with the visible and UV torus observations of others, in order to understand surface--torus interactions. Finally, lunar occultations of M8 in May 1992 and the Rho Ophiuchus cloud in July should provide a wealth of new data concerning young stars.

Publications

Chen, W. P., Howell, R. R., Simon, M., and Benson, J. 10 AU Scale Halo around DG Tauri. *Astrophys. J. Lett.* 387: L43.

Simon, M., Chen, W. P., Howell, R. R., Benson, J. A., and Slowik, D. Multiplicity Among the Young Stars in Taurus. *Astrophys. J.* 384: 212.

Interiors and Atmospheres of the Outer Planets

Lunar and Planetary Laboratory,
University of Arizona

W. B. Hubbard

Strategy

This theoretical/observational project constrains structure of outer planets atmospheres and interiors through observational data. The primary observational tool is observations of occultations of stars by outer solar system objects, which yield information about atmospheric temperatures and dynamics, and planetary dimensions and oblateness. The theoretical work relates the data to interior structures in a variety of ways.

Progress and Accomplishments

We completed the initial phase of analysis of our large data set from the occultation of 28 Sgr by Saturn and Titan. The Titan analysis is essentially complete, and includes 20 light-curves from 13 stations, spanning wavelengths from 0.36 to 0.89 micrometers. We obtained a detailed map of temperature, pressure, haze optical depth, and zonal wind velocity as a function of latitude and altitude, over an altitude range from 250 to 450 km. Haze layers are evident at altitudes of about 300 km in the northern hemisphere, but change abruptly to lower optical depths at Titan latitudes south of -20 degrees. Titan hazes were considerably denser in 1989 than during the 1981 Voyager encounter. Upper atmosphere wind speeds of about 100 m/sec were deduced from the occultation data. For Saturn, we have completed analysis of fiducial ring features used to establish the pole and radius scale of the rings. Our results show good agreement with the pole and radius scale inferred from combined analysis of Voyager RSS and PPS data, and confirm the slight inward shift of the ring radius scale (by about 5 km) with respect to the initial RSS scale.

An attempt to measure the radius of asteroid 4 Vesta by occultation was clouded out. An occultation by 1 Ceres was successfully observed from Tucson, but with insufficient coverage from other stations for useful results.

Anticipated Accomplishments

With an accurate determination of the astrometry of the Saturn occultation now in hand, we move to analysis of the atmospheric structure of Saturn's stratosphere. Inversions will be performed on our data to recover temperature-pressure profiles and high-altitude wind speeds will be inferred using central flash information for Saturn. For Neptune, central flash data will be analyzed to determine the

stratospheric winds and determine whether they are consistent with the winds determined from Voyager images of clouds at lower altitudes.

We will bring on line a new high-speed occultation CCD system, and will use it to observe potential occultations by Pluto and Neptune, and Triton if opportunities occur. A July occultation by Neptune offers an opportunity to remeasure Neptune's ring arcs.

Publications

Gaseous Accretion and the Formation of Giant Planets, M. Podolak, W. B. Hubbard, and J. B. Pollack, in *Protostars and Planets III* (ed. E. H. Levy, J. I. Lunine, and M. S. Matthews), *Univ. of Arizona Press*, 1992.

Interior Structure of Neptune: Comparison with Uranus, W. B. Hubbard, W. J. Nellis, A. C. Mitchell, N. C. Holmes, S. S. Limaye, and P. C. McCandless, *Science* **253**, 648, 1991.

Models of Uranus' Interior and Magnetic Field, M. Podolak, W. B. Hubbard, and D. J. Stevenson, in *Uranus* (ed. J. T. Bergstrahl, E. D. Miner, and M. S. Matthews), *Univ. of Arizona Press*, 1991.

Planetary Interiors, Jovian Planets, W.B. Hubbard, in *The Astronomy and Astrophysics Encyclopedia* (ed. S. P. Maran), Van Nostrand Reinhold, 1992.

Studies of Extended Planetary Atmospheres

Lunar & Planetary Laboratory
The University of Arizona
Tucson, AZ 85716

D. M. Hunten

Strategy

Telescopic observation and analysis of planetary atmospheres (including Moon and Mercury) and the Io torus; occultation observations; supporting laboratory studies.

Progress and Accomplishments

A comprehensive study of sodium and potassium in the lunar atmosphere is in press in *Icarus* (Sprague et al.). Atoms thermalized to the surface temperature are found only near the subsolar point; elsewhere, and everywhere at high altitudes, we see only suprathermals, which can be modeled by a Chamberlain exosphere at about 2000 K. We retain our explanation (Kozlowski et al.) that most atoms adsorb to the surface for a large fraction of a second, to be released by photodesorption in which excess photon energy goes into kinetic energy of the released atom. These results and modeling procedures were also reported at the DPS. We also have suggestive evidence that a southern-hemisphere meteor shower was detected as an enhancement of the lunar sodium in October 1990. The 15-cm coronagraph is now installed in a previously empty dome on Mount Lemmon (about 3 km altitude), but alignment of the coude optics has proven to be more difficult than expected. Nevertheless, we did obtain one spectrum of the lunar atmosphere showing the expected reduction of scattered light. Rizk's water-vapor observations for Mars from 1988-89 were presented in his Ph.D. thesis. Analysis by two different methods demonstrated that migration in latitude is negligible in comparison with local sublimation and deposition. The data have been published (Rizk et al.) and a paper is being prepared on the analysis. Several telescope runs were obtained during the following apparition, but were clouded out except for a single night. This night, however, appears very interesting in that water vapor was below the detection limit. Our successful collaboration with N. Schneider (University of Colorado), in observations of the Io system at the 61-inch, will be reported by him. The work on intra-cavity laser spectroscopy of methane continues to go extremely well but very slowly.

Projected Accomplishments

Observations and analysis of sodium and potassium on the Moon and Mercury will continue. We expect to have the coronagraph operating and taking routine data by early summer, primarily on the lunar atmosphere. It will also have applications to Jupiter, but serious observations will have to await the next apparition centered on March 1993. The occultation program has been rather dormant owing to lack of

opportunities and the final analysis of the Titan results. We will try to observe the Pluto event in May 1992, in the Tucson area. The collaboration with N. Schneider is expected to continue. We also have a run coming up on the Io torus with M. McGrath and R. A. Brown.

Publications

Hunten et al. (lunar meteors), *GRL* 18, 2101 (1991);
Rizk et al. (Mars water), *Icarus*, 90, 205 (1991);

Hunten et al (spectrograph), *PASP* 103, 1187 (1991).

Laser Studies of the Photodissociation Dynamics for the Formation of Cometary Radicals

Chemistry Department
University of California at Davis
Davis, CA 95616

William M. Jackson

Strategy

The purpose of this research is to conduct laboratory test of the theoretical proposal that the C_2 and C_3 radicals observed in comets are formed from the photodissociation of C_2H and C_3H_2 radicals, respectively. Excimer lasers are used for producing the intermediate C_2H and C_3H_2 radicals from stable compounds such as acetylene and allene. The intensity of these lasers is high enough that a significant amount of secondary photolysis leads to the formation of C_2 and C_3 radicals. The intermediate radicals are detected using time resolved infrared emission spectroscopy, while the cometary radicals are detected using the laser induced fluorescence technique. Detailed results are given in the papers referenced below, but briefly, the C_2 product formed from the photodissociation of C_2H has been detected in the $A^1\Pi_u$, $B'^1\Sigma_g^+$, $b^3\Sigma_g^-$, $B\Delta_g$ and $a^3\Pi_u$ electronic states. Significant vibrational and rotational excitation has been observed for the radicals in all of these states. We are now collaborating with a Duadel to determine how these experimental results will affect the theoretical models of cometary C_2 spectra. Similar experiments with allene and propyne have shown that the C_3 is formed rotationally cold.

Publications

William M. Jackson, Yihan Bao, Randall S. Urdahl, "Implications of C_2H Photochemistry on the Modeling of C_2 distributions in Comets", *J. Geophys. Res.*, **91**, 17,569 (1991)

William Jackson, "Recent Laboratory Photochemical Studies and Their Relationship to the Photochemical Formation of Cometary Radicals", *Comets in the Post-Halley Era*, Vol. 1, R. L. Newburn Jr. et al (eds.), p. 313(1991)

Randall S. Urdahl, Yihan Bao and William M. Jackson, "An Experimental Determination of the Heat of Formation of C_2 and the C-H bond Dissociation Energy in C_2H ", *Chem. Phys. Lett.* **178**, p.425 (1991)

Yihan Bao, R. S. Urdahl, and William M. Jackson, "Detection of $C_2(B'^1\Sigma_g^+)$ in the multiphoton dissociation of acetylene at 193nm", *J. Chem. Phys.*, **94**, p. 808(1991).

Laboratory Simulation of the Surface of Halley's Comet

Chemistry Department
University of California at Davis
Davis, CA 95616

William M. Jackson

Strategy

The purpose of this research is to investigate physical mechanism that could be responsible for the jets that are observed in Halley's comet. NH, C₂, and CN emissions are observed from these jets and therefore they must contain free radicals, such as NH, C₂, and CN. The mechanism for the production of free radicals in these narrow jets is still unknown.

Progress and Accomplishments

We have investigated whether these radicals could be produced by photodissociation directly from icy grains. Experimental and theoretical work both confirm that although free radicals could be produced via direct photolysis of icy grains, the yield is too low by many orders of magnitude to explain the observed phenomena. An alternate hypothesis has been developed where these radicals are produced when the grain is evaporated and it release positive and negative ions. The negative ions of the free radicals can easily produce free radicals in the gas phase by photodetachment of the electrons using visible and near UV solar radiation. Since the intensity of solar radiation is much higher in this region of the spectrum than it is in the far UV region the efficiency of the new process will be much higher. Experimental and theoretical studies of this new hypothesis will continue this year.

Anticipated Accomplishments

A pulsed beam-surface apparatus equipped with lasers will be utilized to test this new hypothesis. This year we expect to be able to determine the yield of cometary gases such as CN and C₂ from icy mixtures of water, acetylene, cyanogen, and hydrogen cyanide. Laser induced florescence will be used to detect these radicals in the gas phase at a distance of 1 cm from the surface. The yield of free radicals will be measured as a function of the composition of the ice and the intensity of the ablation laser. The time of flight of the radicals and their internal energy distributions will also be determined. This information should help us to sort out the mechanism involved in the production of the free radicals.

Publications

W. M. Jackson, "Formation of Ions and Radicals From Icy Grains in Comets", accepted for publication in, *Asteroids, Comets, and Meteors III Proceedings*,

Paper #111, Flagstaff, Arizona, Lunar and Planetary Institute.

Physical Properties of Active Comets

Institute for Astronomy
University of Hawaii
Honolulu, HI 96820

David C. Jewitt

Strategy

This is a new, intensive observational study of the morphology and photometry of active comets. The main scientific goal is to relate the observed structure of the inner coma to the spatial and temporal distribution of mass loss from the underlying nucleus. This will hopefully provide a firm basis for the interpretation of the diverse morphologies exhibited by the active comets. The study will synthesize measurements of jets, halos, and other coma structures in comets as a function of heliocentric distance, and amongst comets at a fixed heliocentric distance. We hope to address such simple questions as "why do some comets have jets while others do not?" and "how and why do jets change their characteristics with heliocentric distance?"

Progress and Accomplishments

Time-series imaging observations of several active comets (including P/Schwassmann Wachmann 1, Kopff, Brorsen-Metcalf, d'Arrest, Chernykh) have been analyzed for both morphological and photometric information.

Anticipated Accomplishments

In the coming year, two new UH charge coupled device imagers will become available to this project. These are a 2048 x 2048 Tektronix CCD having 80% quantum efficiency in the red, and a 4096 x 4096 Loral array. These devices will permit cometary imaging studies combining unprecedented sensitivity, resolution and field of view. In addition to the first observations with these devices, we expect to publish results on temporal evolution of jets in the above named comets.

Publications

D. C. Jewitt (1992), "Application of Robotic Telescopes to the Physical Investigation of Comets", Invited review for "Symposium on Robotic Telescopes in the 1990's", held 1991 June 22-24 in Laramie, Wyoming (in press).

J. X. Luu and D. C. Jewitt (1992), "High Resolution Surface Photometry of Near Earth Asteroids", *Icarus*, in press.

Goldstone Solar System Radar

Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109

Raymond F. Jurgens

Strategy

This task provides for the planning, experiment design, and coordination of the data acquisition and engineering activities in support of all Goldstone planetary radar astronomy. Activities related to up-grades of the receiver and transmitter systems, and data processing support systems continue. Also covered in this task is the hardware and software maintenance of the data processing facility (VAX 11/780, array processor, tape drives, user terminals, image display terminal, and a SUN SPARC station) used by many of the GSSR scientific investigators.

Progress and Accomplishments

The radar cone with the new 500kW X-band transmitter was installed ahead of schedule in May, 1991 and was first used in combination with the VLA to study Titan. New GSSR/VLA radar studies included the moons Callisto, Ganymede and Titan, the planet Mercury, Saturn's rings, the asteroids 1991 EE and 324 Bamberga. Monostatic radar observations included Mercury, the Galilean moon Io, the moon Titan, and asteroids 7 Iris, 1991 JX, 1988 BB, 1981 Midas, 4 Vesta. The discovery of Mercurian polar ice caps is one of the highlights of the VLA observations. New work includes the use of cross power spectra to greatly reduce the polarization coupling for determination of the Stokes parameters. The new DSS-13 34m antenna demonstrated significant performance improvement in recent bistatic observations of Mercury. This antenna could be used as either the prime or secondary part of the 4179 Toutatis radar experiment. Work progresses on the Single Horn System for use with close approaching asteroid experiments. We are beginning the conversion of the VAX analysis programs to run on more common computer platforms. A few demonstration programs are now available for the PC under Windows and a planning program using the planetary ephemeris tools on the SUN station.

Anticipated Accomplishments

Goldstone radar cone will be modified to contain a single horn transmit/receive system for close asteroid experiments. The first use of this system is planned for December when the asteroid 4179 Toutatis will have a 25 second round trip light period which is too short for the current double horn system. New observations of Mars and Titan using the Goldstone/VLA combination are scheduled. Observations of Mercury for relativity and polar ice continue. Observations of the lunar poles are

planned to search for polar ice. A new series of Mars observations are scheduled for October through March. New programmed local oscillators (PLO's) should be available for use in May. Some efforts are under way to find a graceful way to replace our aging VAX's with more economical computers. Fast high volume and economical recording media is still a problem.

Publications

Anderson, J.D., M.A. Slade, R.F. Jurgens, E.L. Lau, X X Newhall, and E.M. Standish, "Planetary Ranging Experiments," in *Proceedings Astron. Soc. of Australia*, 9, No. 2, 1992.

Anderson, J.D., et al., "Recent Developments in Solar-System Tests of General Relativity," in *Proceedings of MG6*, 2, Singapore, 1992.

Butler, B., D.O. Muhleman, and M.A. Slade, "Goldstone/VLA Radar Mapping of Mercury," submitted to *Journal of Geophysical Research*, May, 1992.

Grossman, A.W., D.O. Muhleman, M.A. Slade, and B. Butler, "VLA/Goldstone Planetary Radar Results," in *Intl. Symp. on Radars and Lidars in Earth and Planetary Sciences*, pp. 19-22, ESA Special Publication 3289, 1992.

Harmon, J.K., M.A. Slade, and R.S. Hudson, "Mars: Wavelength-Dependent Dual Polarization Global Scattering," MSATT (R.M. Haberle et al., eds.) pps. 65-66, *LPI Technical Report 92-02*, Lunar and Planetary Institute, Houston, TX, 1992, (Also accepted by *Icarus*, April 1992).

Harmon, J.K. and M.A. Slade, "Radar Mapping of Mercury: Full-Disk Delay-Doppler Images," submitted to *Science*, April, 1992.

Ostro, S.J., D.B. Campbell, J.F. Chandler, A.A. Hine, R.S. Hudson, K.D. Rosema, and I.I. Shapiro, "Asteroid 1986 DA: Radar Evidence for a Metallic Composition," *Science*, 252, 1399-1404, 1991.

Ostro, S.J., D.B. Campbell, J.F. Chandler, I.I. Shapiro, A.A. Hine, R. Velez, R.F. Jurgens, K.D. Rosema, R. Winker, and D.K. Yeomans, "Asteroid Radar Astrometry," *Astronomical J.*, 102, 1490-1502, 1991.

Ostro, S.J., "Radar Reconnaissance of Near-Earth Asteroids," in *International Symposium on Radars and Lidars in Earth and Planetary Sciences* (T. Guyenne and J.J. Hunt, E.) ESA SP-328, ESA Publications Division, ESTEC, Noordwijk, The Netherlands, 9-13, 1991.

Slade, M.A., B.J. Butler and D.O. Muhleman, "Mercury Radar Synthesis Imaging at 3.5 cm," submitted to *Science*, April 1992.

Yeomans, D.K., P.W. Chodas, M.S. Keesey, S.J. Ostro, J.F. Chandler, and I.I. Shapiro, "Asteroid and Comet Orbits Using Radar Data," *Astron. J.* 103, 303-317, 1992.

Zisk, S.H., P.J. Mouginis-Mark, J. Goldspiel, M.A. Slade, and R.F. Jurgens, "Valley Systems on Tyrrhena Patera, Mars: Earth-Based Radar Measurements of Slopes," in press, *Icarus*, May 1992.

Infrared Spectroscopy of Jupiter and Saturn

Dept. Earth & Space Sciences
University at Stony Brook

Roger Knacke, PI
K. S. Noll, Co-I

Strategy

Infrared spectroscopy provides unique insights into the chemistry and dynamics of the atmospheres of Jupiter and Saturn, and of Titan, the enigmatic satellite of Saturn. The 5 micron spectral region of these objects is transparent to deep levels, and is therefore particularly useful for the identification of molecules in the deep atmosphere at very low (parts per billion) concentrations. In Titan, 5 micron observations probe atmospheric layers at or near the surface. The observations support and complement VOYAGER and CASSINI measurements. Ground-based spectroscopy is sensitive to lower mixing ratios for selected molecules, while the spacecraft mass and infrared spectrometers probe molecules that are inaccessible from the ground. The ground-based observations also provide time-based data for preparation for the CASSINI mission.

Progress and Accomplishments

In 1990 we initiated 5 micron observations of Titan with the goal of investigating trace molecular constituents and atmospheric structure. These observations revealed the surprising result that Titan appears to be a factor of 2-3 times fainter at 5 microns than it was at the time of the last observations at this wavelength made in 1975. A search of the records of the early observations suggests that they could have been contaminated; we are studying this problem and pursuing new observations to clarify the situation. In 1991 we obtained more data at J, H, K, and M (5 microns), and made repeated observations of the albedo as Titan orbited Saturn. The J albedo is 12+3% greater than the albedo measured in 1979; the H and K albedos are the same. There was no evidence for variations at any wavelength over the Eastern half of Titan's orbit. We also obtained low resolution ($R = 50$) spectra of Titan between 3.1 and 5.1 microns. The spectra contain evidence for CO and CH₃D absorptions. Spectra of Callisto and Ganymede in the 4.5-5.1 micron spectral region are featureless and give albedos of 0.08 and 0.04 respectively. If Titan's atmosphere is transparent near 5 microns, its surface albedo there is similar to Callisto's.

Anticipated Accomplishments

In the coming year we plan to complete the analysis of Titan orbital variability. We have applied for IRTF time to use the ProtoCam near infrared camera for photometry, an important addition being measurements in the western half (not yet measured) of

Titan's orbit. We have obtained two nights of UKIRT time In July 1992 for further intermediate resolution studies of CO. An observing proposal to measure several lines of ^{13}CO and ^{12}CO at extremely high resolution with the IRTF CSHELL spectrometer has also been submitted. We anticipate that we will obtain a complete intermediate resolution spectrum of Titan's 5 micron window, and very high resolution spectra of interesting spectral lines. We will analyze the data for potential links between Titan's surface and atmospheric chemistry, and thus establish clues to the origin of Titan's atmosphere.

Publications

K.S. Noll and R.F. Knacke 1992, "New 1 to 5 micron Observations of Titan," *Icarus*, submitted.

Advanced Infrared Astronomy

Goddard Space Flight Center
Greenbelt, MD 20771

Theodor Kostiuk

Strategy

This task applies infrared heterodyne spectroscopy (IRHS) and other high resolution techniques, as well as infrared array to studies of molecular constituents of planetary atmospheres. High spectral and spatial resolution measurement and analysis of individual spectral lines permits the retrieval of distributions of atmospheric molecular abundances and temperatures and thus, information on local photochemical processes. Determination of absolute line positions to better than 10^{-8} permits direct measurement of gas velocities to a few m/sec and thus, the study of dynamics. Observations are made from ground based observations (e.g. NASA Infrared Telescope Facility on Mauna Kea and Kitt Peak National Observatory).

Progress and Accomplishments

Jupiter- The variability and morphology of the band emission (8-13 μ m) from the principal hydrocarbon constituents (CH_4 , C_2H_2 , C_2H_6) from polar regions was measured simultaneously with IUE observations of UV aurora. Spectral images of H_2 and H_3^+ emission (2-4 μ m) were obtained. Single line emission spectra of ethane and ethylene indicate a distributed enhancement (ethane) and a bright confined peak (ethylene) in the N polar region and temperatures near the N pole $\sim 300\text{K}$ (~ 10 μ bar). The possibility of measuring Jovian planetary oscillations using IRHS measurements of Doppler shifts of H_2 quadruple lines (17 μ m; 28 μ m) was investigated. Oscillation amplitudes ~ 1 m/s are detectable. *Saturn* - Ethane line emission was measured and mole fractions of $\sim 10^{-5}$ (60° N) and $\sim 10^{-6}$ (24° N) were derived. These results were used to test recent photochemical (PC) models and to modify model thermal and mixing profiles. *Neptune* - IRHS data and Voyager IRIS results on ethane were compared in an attempt to optimize the PC model. Good agreement was found and abundance profiles retrieved were within 30% of the PC model results. *Mars* - Analysis of direct measurements of global winds using Doppler shifts of 10 μ m CO_2 lines is underway. *Venus* - The study of global circulation is continuing. Observations of Doppler shifts of mesospheric and thermospheric CO_2 features during opposite phases near Venusian inferior conjunction were repeated in fall 1991.

Anticipated Accomplishments

Observed variability and morphology of the emission from Jupiter's polar regions from the stratospheric constituents CH_4 , C_2H_2 , C_2H_6 (8-13 μ m), 2-4 μ m observations

and UV auroral activity, will be evaluated to investigate the sources and character of the IR emissions, their relationship to auroral activity, their distributions, temperatures and photochemical and diffusion effects. Analysis of the observations of global circulation on Venus and Mars using the 10 μm CO_2 spectra will be completed and will be correlated with mm-wave results. Comprehensive global circulation models will be developed. Ethane abundances on Saturn and Titan will be determined using line measurements. An attempt to measure Titan's global circulation will also be made using C_2H_6 lines. Ozone and water distribution on Mars will be measured during N hemisphere winter (expected ozone maximum) and comparison with 1988 observations will test the PC models and their seasonal variability.

Publications

1991- "Ground Based Measurements of the Global Distribution of Ozone in the Atmosphere of Mars", F. Espenak, M. M. Mumma, T. Kostiuk, and D. Zipoy, *Icarus* 9 2, 252-262.

1991- "Absolute Wind Velocities in the Lower Thermosphere of Venus Using Infrared Heterodyne Spectroscopy", J. Goldstein, M. J. Mumma, T. Kostiuk, D. Deming, F. Espenak, and D. Zipoy. *Icarus* 9 4, 45-63.

1991- "A Self-consistent Picture of Circulation in Venus' Atmosphere from 70 to 200km altitude" J. Goldstein, M. J. Mumma, T. Kostiuk, and F. Espenak. (submitted to *Icarus*).

1992- "On the Detectability of the Jovian Oscillations with Infrared Heterodyne Measurements", B. Mosser, D. Gautier, and T. Kostiuk. *Icarus* (In Press).

1992- "Stratospheric Ethane on Neptune: Comparison of Ground Based and Voyager IRIS Retrievals", T. Kostiuk, P. Romani, F. Espenak, and B. Bezard. (Submitted to *Icarus*).

Imaging and Spectroscopic Studies of Primitive Solar System Bodies

Lunar and Planetary Laboratory
University of Arizona

Stephen Larson

Strategy

The objective of this continuing observational program is to investigate the spectroscopic and morphological characteristics of comets and selected minor planets over a wide range of heliocentric distances as they may suggest or constrain models of cometary processes, their formation environment and evolution. Direct images of all observable comets ($M_v < 22$) and 300-850nm spectra of the brighter ones are obtained (weather permitting) on a monthly basis with our CCD spectrograph/camera. The direct images may be used for astrometry, photometry, and studies of coma and tail morphology. In some cases, anisotropic dust emission can provide information on the nucleus spin vector. Spectra provide data on the strengths of the principal emissions for comparison of dust/gas ratios of a large sample of comets. Long integrations of minor planets in comet-like and nearby orbits are made to search for faint comae.

Progress and Accomplishments

Direct CCD images and sometimes spectra were obtained (and reported in the indicated IAU Circulars) of Comets Arend-Rigaux, Arai (1991b), Chernykh (1991o), Faye (1991n), Giacobini-Zinner (1991m), Grigg-Skjellerup, Hartley (1991j), Hartley 1, Hartley 2 (1991t), Helin-Alu (1991r), Helin-Lawrence (1991l), Howell (1992d; IAUC 5472, MPC 19 913), Kowal (1991i), Kowal 1 (MPC 19 915), Levy (1990c), Levy (1991q), Machholz (1986 VIII), McNaught-Hughes (1990g), McNaught-Hughes (1991y), McNaught-Russell (1991w), McNaught-Russell (1990o), McNaught-Russell (1991y), Metcalf-Brewington (1991a), Mueller (1991h1), Mueller 2 (1990j), Mueller 3 (1990l), Mueller 4 (1992g), Shoemaker-Levy (SL) (1991d), SL 2 (1990p), SL 3 (1991e), SL 4 (1991f), SL 5 (1991z), SL (1991a1), SL 6 (1991b1), SL 7 (1991d1), SL 8 (1992f), Smirnova-Chernykh, Schwassmann-Wachmann 1, Spacewatch (1991x), Takamizawa (1991h), Taylor (1990n), VanBiesbroeck (1989h1), Wild 2 (1989t), and Wirtanen (1991s). Minor planets 1992AD, 1991TB1, 1991EE, 1991JX were observed, but no comae were found. Our measurements of the split comet P/Chernykh each month from September 1991- March 1992 helped Z. Sekanina determine the time of splitting (IAUC 5319). Unlike most split comets, the difference in brightness of the two components decreased over time with the fainter one developing a tail like the primary. A postperihelion search for Comet Mueller (1991h1) indicates that fragments $M_r > 21$ did not survive perihelion passage. A new focal reducer and spectrograph was constructed that provides excellent image quality over a 7 by 11 arcmin field but at the expense of the 300-380nm spectral range. It was designed to accept the f/9 beam

of the Steward Observatory 2.2m telescope and convert it to f/1.8. Collaborating with J. Scotti, the first frames with the 2.2m telescope contained recovery images of P/Howell. The Tumamoc Hill 0.5m telescope was converted to an f/4 Newtonian, and through donations and loans of a Photometrics Ltd. CCD, computer, position encoders and guider, is being configured for rapid response astrometry and photometry of near Earth asteroids and comets. Although located within the Tucson city limits, the system is capable of detecting $M_v=20$ stars in two minutes.

Anticipated Accomplishments

Continued monthly imaging, spectral and astrometric observations of comets and minor planets will be carried out. The analysis of tail morphology of 40 comets at large heliocentric distance is nearing completion.

Publications

Larson, S.M. and Slaughter, C.D. (1992) Evaluating some computer enhancement algorithms that improve the visibility of cometary morphology. Accepted for proceedings of the *ACM'91* conference.

Tegler, S.C., Campins, H., Larson, S.M., Kleine, M., Rieke, M., and Kelly, D. (1992) Simultaneous visible and near infrared spectrophotometry of Comet Austin. Accepted for *Ap. J.*, June 1992.

Sekanina, Z.S., Larson, S.M., Hainaut, O., Smette, A., and West, R.M. (1992) Major outburst of periodic comet Halley at a heliocentric distance of 14 AU. Accepted for publication in *Astron. Astroph.*

Johnson, J.R., Larson, S.M., and Singer, R.B. (1991) Remote sensing of potential lunar resources. 1. Near-side compositional properties. *J. Geophys. Res.*, **96**, E3, 18,861-18,882.

Larson, S.M., Johnson, J.R., and Singer, R.B. (1991) Evaluation of the sensitivity of reflectance ratios to mafic minerals in the lunar regolith. *Geophys. Res. Lett.* **18**, No. 11, 2149-2152.

Johnson, J.R., Larson, S.M. and Singer, R.B. (1991) A reevaluation of spectral ratios for lunar TiO_2 mapping. *Geophys. Res. Lett.*, **18**, No.11 2153-2156.

Showalter, M.R., Cuzzi, J.N., and Larson, S.M. (1991) Structure and particle properties of Saturn's E ring. *Icarus*, **94**, 451-473.

Infrared Observations of Solar System Objects

Lunar and Planetary Laboratory
University of Arizona
Tucson, AZ 85721

Larry A. Lebofsky

Strategy

This program is our ongoing ground-based infrared studies of Solar System objects. This is a broadbased program that includes collaboration with scientists at other institutes and several graduate students at the University of Arizona. Our overall objective is to study the spectral and physical properties of small Solar System bodies. Our work spans the entire Solar System from a study of the mineralogy of Mercury, to several studies of asteroids, and to studies of Triton, Pluto, and Charon. From these studies we hope to understand better the origin and evolution of these bodies and how they fit into the context of the origin and evolution of the Solar System as a whole.

Progress and Accomplishments

In the last year, we have submitted 5 papers for publication (2 published and 2 in press). We also expect to submit 3 papers in the near future on the diameter and thermal properties of Vesta, a book chapter on asteroid studies, and on the near IR spectrum and composition of Mars' satellite Deimos. We have had several successful telescope runs in the past few months on the visual and near IR spectra of dark asteroids and satellites and are presently reducing these data.

Anticipated Accomplishments

Over the next year our work will include: continued studies of dark asteroids and satellites, the distribution of water and other low-temperature materials in the Solar System, the nature of shocked material on asteroid surfaces, the relationship between asteroids and comets, and extensive correlation of all of these observations with laboratory spectra of meteorites.

Publications

Lebofsky et al. (1990), Jones et al. (1990), Marcialis and Lebofsky (1991), Marcialis et al. (1991), Gaffey et al. (1991).

CVF spectroscopy of Pluto: Correlation of composition with albedo, R.L. Marcialis and L.A. Lebofsky, *Icarus*, **89**, 255-263, 1991.

The albedos of Pluto and Charon: Wavelength dependence, R.L. Marcialis, L.A. Lebofsky, M.A. DiSanti, U. Fink, E.F. Tedesco, and J. Africano, *Aston. Jour.*, **103**, 1389-1394, 1992.

Asteroid surface compositions from Earthbased spectroscopy, M.J. Gaffey, L.A. Lebofsky, M. Nelson, and T.D. Jones, in press, 1992.

Overview of the Asteroids, M. Nelson, D. Britt, and
L.A. Lebofsky, in press, 1992.

Solar System Spectroscopy

Department of Physics and Astronomy
Northern Arizona University
Flagstaff, AZ 86011-6010

Barry L. Lutz

Strategy

The research supported by this grant focuses on observational studies of the composition, structure and variability of planetary atmospheres, of satellite atmospheres and surfaces, and of cometary comae as a diagnostic probe of the origin, evolution and current state of the solar system. The techniques used in this research center on spectroscopic observations in the spectral region between 3000 Angstroms and 5 micrometers. In addition to being basic solar system research, these studies provide "ground truth" support of observations of the solar system by NASA's missions, including the Galileo spacecraft, the Hubble Space Telescope and the proposed Cassini mission to the Saturnian system, and provide essential temporal continuity that is required link the *in situ* science from intensive but infrequent missions.

Progress and Accomplishments

The efforts during the prior year were dominated by re-establishing the research program following the move of the Principal Investigator to a new institution. Included in these efforts was the establishment of a new workstation environment to serve the data acquisition, reduction and analysis need of the science program, and the porting of data and analysis software to the new institution. In spite of this initial constraint in the science program, several scientific accomplishments were made:

Recording of new high-resolution, Fourier Transform spectra of Jupiter in search of the trace molecules HCl, HBr, and H₂Se, as diagnostics of chemical and transport processes in the planet's deep interior.

Reduction and analysis of new spectra of Triton and Pluto made in 1991 to study the methane abundances on each and look for seasonal or secular variations of the abundances.

Near completion of the analysis of the molecular ion emissions seen in the coma of comets P/Halley (1986 III) and Bradfield (1987s) for comparison with the ionic component in the comae of previously studied comets.

Completion of an invited review of the two-volume compendium, "Comets in the Post-Halley Era," and acceptance for publication of the review in the journal "Origins of Life and Evolution of the Biosphere."

Anticipated Accomplishments

During the coming year, a number of projects are expected to significantly advance, including

- i) A detailed analysis of the new Jovian spectra recorded in search of HCl, HBr, and H₂Se.
- ii) Completion of the study of the ions in the spectra of P/Halley and Bradfield and submission for publication the results of this study and a comparison of the ionic species in these comets with other comets.
- ii) Completion of the reduction and analysis of the spectra of Triton and Pluto for all years in hand and initiation of a search for and study of secular variations of the methane abundance on each.
- iv) Initiation of a study of chemical effects of ion bombardment and of X-ray irradiation of ice mixtures to predict trace chemical species on ice-covered solar system bodies that could be remotely detected.

Publications

"The Brightness, Albedo, and Temporal Variability of Neptune" (with G. W. Lockwood, D. T. Thompson, and E. S. Howell) *Astrophys. J.* **368**, 287-297 (1991).

"Deuterium on Venus: Observations from Earth" (with C. deBergh, B. Bezard, T. Owen, D. Crisp, and J.-P. Maillard) *Science* **251**, 547-549 (1991).

"Gas and Dust production by Comet Halley (1910 II)" (with E. S. Howell, and V. M. Slipher) *Astrophys. J.* **371**, 776-784 (1991).

"Book Review: Comets in the Post-Halley Era" (with Susan Hoban) *Origins of Life and the Biosphere* (in press).

Astrometric Observations of Comets and Asteroids and Subsequent Orbital Investigations

Smithsonian Institution Astrophysical Observatory
Cambridge, MA 02138

B. G. Marsden

Strategy

CCD astrometric observations are made with the 1.5-m reflector at the Oak Ridge Observatory.

Progress and Accomplishments

Out of nine scheduled observing nights each month, six or seven were generally at least partly usable, although two months this past year allowed only four nights and one month the very rare occurrence of only two nights. The average number of successful observations on a night used was 55. The record night brought 111 observations and the record month 469 observations. Even for the record month, reductions were completed in three days and the results published within a month. The dead time between exposures in different parts of the sky is now typically down to only 100 seconds. Thirty-two different comets were observed during the year, ten of them within days of discovery/recovery, and in seven cases we made the very last observations. Twelve new Earth-approaching minor planets were observed, and in five cases we made the last observations. Last-minute astrometry of 1991 JX (on an additional night made available by special arrangement) ensured the success of radar detection. Observations were also made of ten numbered Earth-approaching minor planets, as well as of (243) Ida and (951) Gaspra in connection with Galileo mission; as of the Galileo encounter in October 1991, 46 percent of the published astrometric observations of the past six years were made in the course of this program. Observations at Oak Ridge were made of as many as 69 percent of the minor planets that were newly numbered during the year, and 34 percent of the new numberings were made solely because of Oak Ridge observations. In spite of the poorness of Massachusetts skies for photometry, some attempt has been made to obtain simultaneous photometric data using the standard filters, but the longer exposures necessary to do this seriously greatly cuts down on the number of observations made. Photometry was therefore basically restricted to an occasional collaborative attempt to secure data on moderately bright, new supernovae.

Anticipated Accomplishments

Observations are expected to continue much as usual and as occasion demands. The program is probably now operating at near-peak efficiency.

Publications

4230 observations were published on 129 Minor Planet Circulars and 11 IAU Circulars. Orbit computations were in the same publications.

As far as observations are concerned, the MPCs have been declared a refereed journal, and observations from Oak Ridge plates are contained on MPC Nos. 17854-17856, 17908-17913, 18011-18014, 18062-18068, 18165-18167, 18209-18212, 18325-18326, 18352-18356, 18492-18496, 18566-18574, 18665-18668, 18741-18747,

18850-18853, 18918-18925, 18972, 18980, 18993-18994, 19056, 19066-19071, 19200-19206, 19359-19366, 19370, 19440-19447, 19560-19564, 19631-19638, 19727-19731 and 19783-19787.

The Radial Velocity Search for Extrasolar Planets

Lunar and Planetary Laboratory
Space Sciences Building
University of Arizona
Tucson, AZ 85721

Robert S. McMillan

Strategy

Our radial velocity observations now span 5 years, a time scale comparable to a planetary orbital period. Over 2,040 observations of 16 stars similar to the sun have been accumulated and most of the data have been run through preliminary reductions.

Progress and Accomplishments

We are taking an extremely conservative approach to this business of planet-hunting, because of the extraordinary implications of such findings. Our intensive observing is to quickly reveal short time scale phenomena and minimize the random errors. To determine the long-term systematic errors of the program, we have been observing the solar spectrum as reflected off the lunar crater Mosting A. The overall standard deviation of our 486 observations of the Moon spanning 4.9 years is ± 7.8 m/s. The internal consistency, or "random" error of observations of the Moon within one night is ± 5.2 m/s. Since the external (absolute) calibration of the interferometer is ± 6 m/s and the two error sources add quadratically, there is not much room left for variations intrinsic to the Sun. The data series runs from 1987 April through 1992 February, during which daily sunspot counts increased almost an order of magnitude and are now well past the maximum of activity of Cycle 22. Nevertheless, the Moon velocity data indicate the integrated disk of the solar photosphere in violet absorption lines has been stable to better than ± 3 m/s over this interval. This contradicts the belief that the solar spectrum is too unstable to reveal the small Doppler shifts induced by planets.

Anticipated Accomplishments

Not all of our target stars appear to be constant in velocity. As the length of our data series increases, new observations with the unaltered instrument become more and more valuable because they increase the amplitude sensitivity and frequency resolution in the series' periodograms. We propose to continue observing our present targets and add more to our list.

With funding from the NASA "Origins" Program, we are designing a new radial velocity instrument to be even more stable than our 1986-vintage instrument. We have reviewed the principles of all extant high-precision radial velocity techniques and

find that the Fabry-Perot etalon in transmission is still the only one that controls **both** the wavelength scale and the wavelength broadening function, and which has demonstrated systematic errors less than 10 m/s on a multi-year time scale. Better temperature regulation, more compact packaging, simpler and smaller amplitude tilt-tuning, and a solid etalon in a passive housing characterize our new approach.

Occultation Studies of the Solar System

Lowell Observatory
1400 W. Mars Hill Road
Flagstaff, AZ 86001

Robert L. Millis

Strategy

Occultations of stars by planets, satellites, planetary ring systems, and asteroids offer opportunities to study the occulting bodies in ways not otherwise possible from the surface of the Earth. For example, one can detect even an extremely tenuous atmosphere and can measure the temperature and density profiles of the atmosphere in regions not ordinarily sampled by spacecraft. Occultations also permit direct measurement of the size and shape of solar system objects too small to be directly resolved by ground-based telescopes. The accuracy of such determinations is typically 1% - 2% and, moreover, is independent of the distance to the object. In this investigation, we identify upcoming occultations through wide-ranging computer searches, provide accurate predictions for the more important events and observe selected occultations with our specially designed portable photometric equipment.

Progress and Accomplishments

Work continued on the analysis of the complete occultation data set from the 1988 Pluto occultation. The data reduction is now complete and the paper is almost ready for submission. A paper giving occultation predictions of catalog stars by asteroids, planets, and satellites in 1992 and 1993 was written and is in press. Initial maps of Pluto and Charon, based on their mutual occultations and eclipses, were completed. These maps will be especially important in determining an accurate astrometric correction from the observed center-of-light of the merged Pluto/Charon image as measured on photographic plates to the precise locations of each object. Work so far confirms that the correction is important, but the dataset upon which the maps are based is still too limited and more work is required. A new CCD occultation photometer is under development. The overall system design is nearing completion and the camera head and read-out electronics are in hand.

Anticipated Accomplishments

We will investigate improved techniques for predicting occultations by outer solar-system bodies such as Titan, Triton, and Pluto. The potential of strip scanning and large-format CCDs for this type of ultra-high-precision astrometry will particularly be explored. The CCD occultation camera will be completed and tested this year, and may see its first occultation use in conjunction with the October 1993 appulse of the star P20 and Pluto. The analysis of the 1988 Pluto occultation will be published and

predictions of occultations of catalog stars by asteroids in 1994 and 1995 will be computed.

Publications

Wasserman, L.H., Bowell, E., and Millis, R.L. (1992). "Occultations of Stars by Solar System Objects. IX. Occultations of Catalog Stars by Asteroids, Planets, and Major Satellites in 1992 and 1993," *Astron. J.*, (in press).

Buie, M.W., Tholen, D.J., and Horne, K. (1992). "Albedo Maps of Pluto and Charon: Initial Mutual Event Results." *Icarus*, (in press).

Planetary Studies

California Institute of Technology
Duane O. Muhleman

Strategy

Microwave emission, which is thermal in origin, is mapped with broadband continuum instruments and with high resolution spectral line instruments to investigate planetary and satellite atmospheres, planetary and satellite surfaces and Saturn's ring system. Continuum observations are made with the Very Large Array (VLA) of the deep atmospheres of the major planets at wavelengths in the range from 1 cm to 21 cm where the thermal emission levels are as deep as 100 bars on Neptune. We have carried out a new measurement campaign on Saturn in association with Dr. Arie Grossman at the University of Maryland. A new warm belt in the atmosphere of Saturn which is apparently associated with the great Saturn Storm of 1990-91 was discovered by us in the fall of 1991, well after the visible effects of the storm had subsided. This work is not yet ready for publication. We have renewed our efforts to "map" the Neptune atmosphere at the VLA but we can just get of order ten pixels on the disk. This work is in collaboration with Dr. Mark Hofstadter who is currently an NRC at JPL, after completing his PhD late 1991 with Professor Muhleman under this grant.

Progress and Accomplishments

While much remains to be done with continuum investigations of the atmospheres of the major planets, greater opportunities exist for us in microwave spectroscopy of planetary atmospheres. We carry out high spatial resolution measurements with the Millimeter array at the Owens Valley Radio Observatory (OVRO) in the CO and HCN spectral lines and at the VLA in the 22 GHz line of water vapor. In collaboration with Dr. R. Todd Clancy (University of Colorado), Muhleman has continued their program of monitoring the atmospheric temperatures of Venus (mesospheric levels) and the complete atmosphere of Mars using disk-averaged measurements at the Kitt Peak 12 Meter. The most recent publication on this work is Clancy and Muhleman (1991). Measurements are made of the absorption lines in the first two rotational transitions of the common isotope of CO and in the 1-2 transition in the carbon 13 isotope of CO. The use of 3 lines with very different optical depths in the atmospheres allows us to separately estimate the CO abundances and the temperature profiles. The results are quite complex but in essence, they show that the upper atmospheric temperatures on Venus vary by as much as 20 K relative to the Pioneer reference model and that similar variations occur on Mars, associated with the dust loading in the atmosphere. We find that when the martian atmosphere is relative clear of dust, the temperature profile approaches the radiative equilibrium curve, far different from the Viking Mars Reference profiles based on data from the Viking descents and the Orbiter.

The Millimeter Array at the OVRO consists of 3 telescopes of diameter 10.5 meters which operate as a rotational synthesis, phase coherent array at wavelengths as short as 1 mm. The instrument will have 4 telescopes in fall of 1992 and 5 for the next year. The current instrument was used to make synthesis maps of Venus and Mars in 1988 and 1990, in the first rotational line of CO. Our primary interest is to use the CO molecule as a tracer to measure winds from the doppler shifts of these lines at spatial resolutions of about 3 arc sec. Such winds have NEVER been measured on Mars and the winds on Venus had previously been measure up to altitudes of about 70 km (from the lateral motions of the Pioneer Venus entry probes). Because of the limitations of just three telescopes, the observations had to be built up with four physical moves of the 3 antennas over a week. The data are then corrected to a common distance and mapped in each filter channel. The analysis is complete from the Venus experiment and the results were presented in Shah, Muhleman and Berge (1991). Ms. Shah completed her PhD with Professor Muhleman under support from this grant in the fall of 1991 and is currently an NRC at GISS. We found that the 4-day, superrotation zonal winds (in 1988!) continue up to an altitude of 100 km at speeds as high as 100 m/sec. This results is contrary to theoretical investigations of what the high altitude winds should do based on a small amount of Pioneer Venus thermal IR sounding data which were interpreted in terms of the thermal wind equation. Either that approach is far from correct for Venus or the wind fields change with time. The former seems by far to be the most likely. The experiment will be repeated when we have a 5 telescope array which will yield even better results. The Mars wind work is well along with the lead being taken by Dr. Glenn Berge. We have maps of the CO spectra in 3" cells but we have not completed the absorption line model fits to estimate the component of the wind in the direction toward the Earth, a very labor intensive task due to nearly endless calibrations and compromises.

Anticipated Accomplishments

Professor Muhleman in collaboration with Dr. Clancy and Dr. Grossman, have developed a new technique for measuring water vapor in the atmospheres of Mars and Venus. We simultaneously make maps of the planets in 16 spectral channels (~1.5 MHz res) centered on the 22 GHz water transition. A map of the continuum is made by averaging the channel maps, excluding the central 3 which have most of the effects of the water vapor emission and/or absorption. The differences of the channel maps minus the continuum map clearly reveals the water vapor in emission in the atmosphere around the planet's limb. For Mars, we found over a factor of 2 less water in the atmosphere than that predicted from Viking measurements for the same martian season. As with the winds on Venus, we can't be sure that Mars does not change by that much over time or if the Viking observations have not been correctly interpreted. Clearly, this is a major issue for Mars planetology and is very important for Mars Observer which will make similar measurements of water vapor as done on Viking. We carried out the same experiment on Venus in the fall of 1991 but the data analysis has been going very slowly. The Mars work will be published in the very near future.

Publications

Clancy, R.T., Muhleman, D.O. and G. Berge, G.L. Global Changes in the 0-70 km Thermal Structure of the Mars Atmosphere Derived from the 1975-1989 Microwave CO Spectra *J. Geophys. Res.*, **95**, 14,543-14,554, 1990.

Clancy, R.T. and Muhleman, D.O. Long Term (1979-1990) Changes in Thermal, Dynamical and Compositional Structure of the Venus Mesosphere as Inferred from Microwave Spectral Line Observations of ^{12}CO , ^{13}CO and C^{18}O , *Icarus*, **18**, 129-146, 1990.

Shah, K.P., Muhleman, D.O. and G.L. Berge. Measurement of Winds in the Venus Upper Mesosphere Based on Doppler Shifts of the 2.6 mm CO Line, *Icarus*, **93**, 96-121, 1991.

Muhleman, D.O. and G.L. Berge, Observations of Mars, Uranus, Neptune, Io, Europa, Ganymede and Callisto at a Wavelength of 2.66 MM. *Icarus*, **92**, 263-272, 1991.

Muhleman, D.O. and R.T. Clancy, Microwave Spectroscopy of Mars, *Applied Optics*, in press, 1992.

Muhleman, D.O. and R.T. Clancy, Retrieval of Atmospheric Parameters in Planetary Atmospheres from Microwave Spectroscopy, Chap. 9 in *Remote Sensing with Microwave Radiometry*, John Wiley & Sons, in press, 1992.

Planetary Radar Astronomy Using the Very Large Array

California Institute of Technology

Duane O. Muhleman

Strategy

We are studying the near surfaces of Mercury, Venus, Mars, the Galilean satellites, Titan and Saturn's rings by mapping the complete spatial distribution of radar echoes with the Very Large Array (VLA) near Socorro, NM. The solar system objects are continuously illuminated with a monochromatic signal at a wavelength of 3.5 cm from the NASA/JPL 70 Meter antenna at Goldstone, CA. The transmitted power (450,000 watts) is slightly tuned to allow for the differential doppler shifts over the complete ray path such that the echo at the VLA is stopped in doppler frequency space. The echoing source can then be treated as a natural radio emitter and the spatial distribution of the energy is mapped using Earth rotation, supersynthesis techniques and all the software which supports the VLA. During the 3 years of the program, all of the objects have been successfully imaged with the VLA/JPL radar. Initial papers have been published on Mars and Titan, a paper on Venus is in press and a pair of papers on Mercury have been submitted for publication. All are listed in the attached bibliography.

Progress and Accomplishments

Our Mars work continues on the original data set and it forms the core of Bryan Butler's PhD thesis. In addition, we have planned an extensive experiment for the Mars opposition at the end of 1992 when we will remap Stealth at normal incidence, have a good view the north polar ice cap and will map the Elysium complex which we could not reach in the first experiment. The VLA will be in its larger configuration offering a resolution at the subEarth point of about 90 km. These maps, in addition to our original maps of Stealth and the Residual South Polar Ice Cap will be important for targeting experiments on Mars Observer. We have a suggestion from our original data that another stealth region exists near Elysium. Such features (which show no echo) have not been found elsewhere in the solar system.

Our most recent discovery was the detection of what is nearly certainly ice on the north pole of Mercury. The obliquity of Mercury is zero, the Sun is always on Mercury's equator. If Mercury were a smooth sphere, an observer on a pole would always see a small crescent of the Sun on his horizon. The slightest depression, crater, crack, etc. would NEVER be illuminated by the Sun. The temperatures in such places would be determined by scattered photons, heat conduction from the interior and some horizontal heat conduction. The temperatures could be as low as 50° K. Ice sheets would be stable for millions of years if the temperatures are below 120°K. The geometry of the Mercury-Earth orbit allowed us to see down on the regions since our

angle to the north pole was 11 degrees. We will carry out a south pole experiment when the geometry of the Earth/Mercury system and the VLA configuration are correct in 3 years. We plan to map Caloris with the VLA/JPL radar in Nov of 1992.

We recently carried out a successful campaign on Saturn's rings in collaboration with Dr. Arie Grossman at the University of Maryland. The data are good but the analysis is incomplete due to the pressure of what we regard as more timely radar projects. The goal here is to find reflectivity difference in the ring system which would be caused by variation in the ice-to-dust ratio with distance from Saturn.

A more urgent radar problem is Titan! We have observed it at the last three Saturn close approaches and have 7 days scheduled for July of 1992. Titan is very small and at great distance (> 9 au); it appears as a point source even to the VLA/JPL radar. During each opposition we measure the variation in the surface reflectivity as Titan rotates under the Earth with a 16 day period. In addition to proving the Titan is not covered with a universal ocean of liquid hydrocarbons, we have found one region which is nearly a 50 percent reflector, looking much like a Galilean satellite. Elsewhere, the satellite is no more than a 10 per cent reflector. Furthermore, the timing of the passage of the radar bright region suggests that Titan is rotating with slightly faster than Saturn-synchronous rotation. That result is consistent with the large eccentricity of Titan's orbit. However, are the low reflecting regions large lakes of liquid ethane and methane? If so, are we resolving these structures? Clearly, all of this is very important for planetology in general and the Cassini mission in particular.

Anticipated Accomplishments

Our radar observations of Venus are hampered by the factor of 10 atmospheric absorption on our signals but we have been successful in making the first depolarized maps of the Venus globe. Muhleman is using this in his Magellan work (Guest Investigator) in an effort to understand the high altitude, strong backscattering but low emission regions on the planet. These have been interpreted as regions with metal-like dielectric constants but our approach is to argue that their unusual radar and emission properties are caused by multiple scattering in highly friable materials. These surfaces behave like the ices on the Galilean satellites but are certainly not ice on Venus. VLA maps will be made in the near future to better address these issues and help explain the Magellan measurements.

Publications

Muhleman, D.O., Butler, B.J., Grossman, A.W. and M.A. Slade. Radar Images of Mars. *Science*, **253**, 1508-1513, 1991.

Tryka, K.A., Muhleman, D.O., Butler, B., Berge, G., Slade, M. and A. Grossman. Correlation of Multiple Reflections from the Venus Surface with Topography. *Lunar Science Conference XIII*.

Grossman, A.W., Muhleman, D.O., Slade, M.A. and B.J. Butler, VLA/Goldstone Planetary Radar Results,

Intl. Proc. on Radars and Lidars in Earth and Planetary Sciences, Cannes, France, 2-4 Sept., 1991, (ESA SP-328).

Tryka, K.A. and D.O. Muhleman, Reflection and Emission Properties of Alpha Regio, *J. Geophys. Res.* in press 1992.

Simpson, R.A., Harmon, J.K., Zisk, S.K., Thompson, T.W. and D.O. Muhleman, Radar Determination of Mars Surface Properties. In *Mars*, Univ. of Arizona Press, in press, 1992.

Butler, Bryan, Muhleman, D.O. and M. Slade, Radar Detection of Ice on Mercury and its Stability. Submitted to *J. Geophys. Res.*, 1992.

Slade, M., Butler, B. and D.O. Muhleman, Radar Observations of Mercury. Submitted to *Science*, 1992.

Investigation of Comets at Infrared Wavelengths

**Laboratory for Extraterrestrial Physics
NASA Goddard Space Flight Center
Greenbelt, Maryland 20771**

Michael J. Mumma (P. I.),

Michael A. DiSanti, Susan Hoban, Dennis C. Reuter, and Elizabeth E. Roettger

Strategy

Cometary nuclei are the least processed bodies in the solar system, and they provide a crucial link between the formative processes which influenced chemical evolution in the solar nebula and those which are active in star- and planet-forming regions today. The abundances of volatile and organic refractory components and their distributions within active regions of the cometary nucleus are explored using infrared spectroscopy.

Remote studies of the composition of cometary nuclei are based on spectroscopy and radiometry of the dust and volatiles in the coma. Historically, the volatile parents of observed radicals and ions could be identified in only a few cases, notably water and carbon dioxide (the parents of H, OH and CO_2^+). Direct quantitative detections of candidate parent volatiles were limited to CO in two comets (West 1976 VI and Bradfield 1979 X), along with a few tentative detections of other species at radio wavelengths. In recent years, the combination of improved understanding of spectral line formation in the coma and advances in instrumentation has enabled remote spectroscopic study of parent volatiles at infrared and millimeter wavelengths (for a review, see Mumma et al. 1992). Quantitative detections of H_2O , CO_2 , H_2CO , CH_3OH , H_2S , HCN, and CO were obtained. CH_4 was provisionally detected in a new comet and sensitive upper limits were set for it in two other comets. The detection of CH_3OH at $3.52\text{ }\mu\text{m}$ led to predictions that a major fraction of the $3.4\text{ }\mu\text{m}$ "organic grain" feature was due to volatile fluorescence from two other vibrational bands of CH_3OH , and not solely to thermal emission from the population of organic grains (CHON) discovered in comet P/Halley, as originally thought (Hoban et al. 1991; Reuter 1992).

Progress and Accomplishments: Cometary Observing Program:

The detection of parent volatiles at infrared wavelengths is intimately connected with advances in instrumentation. Two dimensional infrared spectroscopy was first made available when CRSP, developed by Dick Joyce at KPNO, became available as a facility instrument in 1989. CRSP is a cryogenic grating spectrometer with a 2-D (58x62) InSb detector array in the focal plane with a spectral resolving power of ~ 1200 . Using it, we opened the $1\text{--}5\text{ }\mu\text{m}$ region of cometary spectroscopy with improved sensitivity and simultaneous spatial registration of many pixels. We began observations with this instrument on comet P/Brorsen-Metcalf in 1989, and continued with observations of comets Okazaki-Levy-Rudenko (1989r), Austin (1990 V), Levy (1990 XX), and P/Swift-Tuttle (1992t). This work identified the ν_3 band of cometary methanol as the progenitor of the $3.52\text{ }\mu\text{m}$ emission feature in comets (Hoban et al.

1991), and set upper limits to the H_2CO production rates in several comets (Reuter et al. 1992).

Methanol is now recognized to be a major carbon-bearing volatile in comets. In comet Austin (1990 V), for example, methanol (at 5%) was more abundant than carbon monoxide. Our group detected methanol in one periodic comet (P/Brorsen-Metcalf), one new comet (Austin, 1990 V) and one comet with an ill-determined orbital history (Levy, 1990 XX). The methanol abundance (relative to water) varied within this sample, with Austin having a much higher production rate. Methanol production rates retrieved from the $3.4\text{ }\mu\text{m}$ feature in comet P/Halley and Wilson support this trend: that new comets have a significantly higher relative abundance of methanol than do periodic comets.

We also searched for cometary CO and OCS, using the NASA Infrared Telescope Facility and the IRSHELL cryogenic grating spectrometer developed by J. Lacy of the University of Texas. Spectra of comet Austin (1990 V) were acquired at a resolving power of $\sim 13,000$. We achieved a probable detection of CO (DiSanti et al. 1992a), and set sensitive upper limits to OCS in comet Austin (DiSanti et al. 1992b). The observations of the OCS yielded a $3\text{-}\sigma$ upper limit to its abundance of $\sim 4 \times 10^{-3}$ relative to H_2O (DiSanti et al. 1992b). This falls between limits found by others for comets Levy 1990 XX (2×10^{-3}) and for P/Halley (8×10^{-3}). We expect to detect CO and OCS routinely in future comets using more sensitive instrumentation now available at IRTF and UKIRT. We searched for a hot band of H_2O in comet Shoemaker-Levy (1991a1) in July, 1992 with CSHELL at IRTF, but this comet was fainter than initially expected.

Progress and Accomplishments: Theoretical Investigations

Cometary parameters such as total production rate, rotational and kinetic temperatures, and the nature of direct and extended sources are obtained mainly through analysis of cometary spectra. The extraction of these quantities depends on accurate and appropriate models. Until now, virtually all analyses have been based upon a simple model that assumes spherically symmetric outflow of uniform velocity in the coma. However, as was demonstrated for comet P/Halley, the production of parent volatiles is not spherically symmetric nor is the velocity field a simple scalar. As we develop the methods for directly measuring fluorescence from parent volatiles, the need for a more sophisticated model becomes more urgent. For example, the first spatially resolved spectral map of a parent volatile was obtained for methanol in comet Austin 1990 V using the CRSP spectrometer, and it revealed that the distribution of this molecular material differed from that of the dust (Hoban et al. 1991). Many more such studies will follow as the new array-based spectrometers are applied to cometary problems. For this reason, we have been developing a new model which includes asymmetric production from the nucleus, variable temperature and velocity fields in the coma, and realistic treatment of photolytic heating. Mr. Xingfa Xie (Univ. of Penn., Dept. of Astron.) is developing this model for his Ph. D. thesis while in residence at Goddard and the University of Maryland.

The approach is to first develop an isotropic outflow model, then extend it to axisymmetric outflow. The model uses a hydrodynamic code in the inner coma, and a Monte Carlo approach in the outer coma. The isotropic model has been successfully

run on the Cray Y-MP at Goddard. Acceptable agreement between the modelled temperature profiles and measured profiles for comet P/Halley have been achieved.

Projected Accomplishments:

Serial measurements of the production rates of parent volatiles are intended, on both dynamically new and periodic comets. The intent is to study the radiation-processed layer and the transition region between it and the pristine cometary material in new comets, and to investigate the degree of internal heterogeneity in the nuclei of short period comets. The observational work will be augmented by theoretical investigations of fluorescence efficiencies and of axisymmetric coma models. The model is now being applied to velocity distributions in the coma.

Publications:

- DiSanti, M. A., M. J. Mumma, and J. H. Lacy 1992. A sensitive upper limit to OCS in comet Austin (1989c1) from a search for v_3 emission at $4.85 \mu\text{m}$. *Icarus* 97:155-158.
- DiSanti, M. A., M. J. Mumma, J. Lacy, and P. Parmar 1992. A possible detection of infrared emission from carbon monoxide in comet Austin (1989c1). *Icarus* 96:151 - 160.
- Hoban, S., Mumma, M. J., Reuter, D. C., DiSanti, M., Joyce, R. R., and Storrs, A. 1991. A tentative identification of methanol as the progenitor of the $3.52 \mu\text{m}$ feature in several comets. *Icarus* 93:122-134.
- Mumma, M. J., Weissman, P. R., and Stern, S. A 1992. Comets and the Origin of the Solar System: Reading the Rosetta Stone. In *Protostars and Planets III* (Univ of Ariz. Press). eds. Lunine, Levy, and Matthews (in press).
- Reuter, D. C 1992. The contribution of methanol to the $3.4 \mu\text{m}$ emission feature in comets. *Ap. J.* 386, 330-335.
- Reuter, D. C., Hoban, S., and Mumma, M. J. 1992. An infrared search for formaldehyde in several comets. *Icarus* 95:329-332.

Study of Cometosheath Composition and Dynamics using Data Obtained by the Giotto Ion Mass Spectrometer

Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109

**M. Neugebauer, PI;
B. E. Goldstein, and R. Goldstein, Co-I**

Strategy

Data obtained by the Ion Mass Spectrometer (IMS) flown on the Giotto spacecraft in March, 1986, are used for studies of the physics and chemistry of ions in a cometary plasma.

Progress and Accomplishments

Completed a comparison of the plasma parameters (density, temperature, and vector velocity of protons, alphas, and water-group ions) observed by the IMS and similar parameters observed by the JPA instrument on Giotto. Demonstrated that some of the published JPA results were spurious. In the process, discovered a period of differential flow between solar wind and cometary plasmas.

Anticipated Accomplishments

The Giotto IMS data reduction and analysis effort will be completed and the principal conclusions will have been published by the end of FY92. Future work, funded under a separate proposal, will be of a more theoretical nature, drawing on the total set of observations made by several spacecraft and several instruments.

Publications

Fuselier, S., et al., Observations of solar wind ion charge exchange in the comet Halley coma, *Astrophys. J.*, 379, 734, 1991.

Geiss, J., et al., Interpretation of the ion mass spectra in the mass range 25-35 obtained in the inner coma of Halley's comet by the HIS sensor of the Giotto IMS experiment, *Astron. Astrophys.*, 247, 226, 1991.

Goldstein, B. E., et al.: Observations of plasma dynamics in the coma of P/Halley by the Giotto Ion Mass Spectrometer, *J. Geophys. Res.*, 97, 4121, 1992 (Funded by Code SS).

Goldstein, R.: Comment on 'Ion acceleration at the contact surface of comet P/Halley' by C. Gurgiolo and J. D. Winningham, *J. Geophys. Res.*, 96, 11641, 1991.

Goldstein, R., et al.: The Composition and Plasma Signature of a Large Dust Impact on the Giotto Spacecraft, *J. Geophys. Res.*, 96, 13739, 1991.

Neugebauer, M., et al.: A different view of plasma flow inside P/Halley, *Astronomy and Astrophys.*, in press, 1992.

PHYSICAL PROCESSES IN COMETS

Jet Propulsion Laboratory
4800 Oak Grove Dr.
Pasadena, CA 91109,

Ray L. Newburn, Jr.

Strategy

Post-Halley, comets are known to be irregular objects, with most nucleus activity very localized and with the dust coma capable of fragmentation and apparently a source of gas. Older one-dimensional strategies, which assume steady isotropic outflow of material, can give poor time-and-space-averaged results, at best. With two-dimensional data, images through interference filters, one can hope to see dust structures that give evidence of the proper geometry for data reduction, study gradients along the axes of symmetry and look for evidence of fragmentation, and seek evidence for gas abundance gradients associated with the dust. High quality data from brighter comets can then be used to suggest improved data reduction procedures for fainter ones. To obtain such data, image-quality interference filters have been procured for use with a CCD camera at Lick Observatory, where the scale of the 1m Nickel reflector is ideal for brighter comets. Whenever possible, data is taken simultaneously with other telescopes and equipment, especially spectroscopy at the Lick 3m or infrared photometry at the IRTF on Mauna Kea.

Progress and Accomplishments

Massive computer processing of the data sets obtained on comets Austin and P/Brorsen-Metcalf has been undertaken. The availability of simultaneous high resolution spectra from the 3m Shane reflector, extensive flat-fielding in each filter, and dark sky fields as well have resulted in very high quality relative photometry (~1%) but only moderately good absolute photometry (~15%). The clear field of the available CCD is only about six arc-minutes, and these comets both were very near the Sun in the morning sky. As a result there is some uncertainty in the level of the surrounding sky background, and no standards could be acquired during or after the comet observations. Preliminary results on Austin were presented to the DPS. Final processing, monochromatic images, and graphs of absolute radial and azimuthal averages of the dust, C2, [OI], and red CN, currently are being produced.

Anticipated Accomplishments

The massive amount of data in the IHW Halley Archive will be used to improve the data reduction theory for observations of Halley, Austin, and all comets, by testing and

calibrating predictions with the S/C observations. A large quantity of data acquired over the past several years will be submitted for publication. Observations will be attempted during the very favorable apparitions of P/Schaumasse, in March 1993, and P/Ashbrook-Jackson, in July 1993, which come to perihelion very near opposition. These will be the final tests of our observing techniques before the very large number of favorable apparitions in 1994-95.

Infrared Observations of Planetary Atmospheres

Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Drive
Pasadena, CA 91109

Glenn S. Orton (PI)
Kevin H. Baines, A. James Friedson
Padmavati A. Yanamandra-Fisher

Strategy

The goal of this effort is to acquire infrared astronomical data on temperature, composition, and cloud structure of planetary atmospheres. Our investigation supports planetary missions by providing (1) a quantitative baseline required for designing optimum spacecraft *in situ* and remote sensing experiments, and (2) an extension of observational coverage into spatial, temporal, spectral range and spectral resolution domains not covered by spacecraft experiments.

Progress and Accomplishments

In the last three years, we continued thermal imaging of Jupiter and Saturn to derive temperatures and cloud properties and their changes. We observed Jupiter at high spectral resolution (7 - 20- μm) to determine atmospheric structure, composition and isotopic ratios. We tested a high-resolution 1- to 5- μm spectrometer, and initiated collaborative work on spectral imaging of Jupiter at 0.5- cm^{-1} resolution. We obtained high spatial-resolution 1.6-to 5.2- μm images of Jupiter. We presented results on: spectral imaging of Jupiter showing hot spots in C_2H_2 , C_2H_4 , and C_2H_6 a correlation of thermal and reflection properties of Jupiter's clouds, the influence of Saturn's equatorial storm on stratospheric temperatures, and preliminary high-resolution spectroscopy of Titan. We published high-resolution spectroscopic observations of Neptune.

Anticipated Accomplishments

Imaging of Jupiter and Saturn in the thermal and near infrared will continue, making use of camera systems, as available. We will initiate work on observations of Saturn for temperature structure and C_2H_6 distribution, and initiate work on Jupiter's cloud properties. We will observe Saturn and Titan at high spectral resolution. We will publish the results of tropospheric temperature sounding of Jupiter and high-resolution spectroscopic imaging of Jupiter in 1989.

Publications

Orton, G. S., T. Z. Martin, A. J. Friedson, J. Caldwell 1991. Thermal images of Venus at 8 - 22 μm at the time of the Galileo encounter. *Science* **253**, 1536-1538.

Orton, G.. 1991. Ground-based observations of Titan's thermal spectrum. ESA Special Publication. In press.

Orton, G., J. Lacy, J. Achtermann, P. Parmar, A. Castillo 1991. High-resolution spectroscopic thermal infrared images of Jupiter in 1989 October. *Bull. Amer. Astron. Soc.* **23**, 1131.

Orton, G., A. J. Friedson, T. Kanamori, T. Thaller, R. Beebe, L. Huber, J. Caldwell 1991. Time-dependence and spatial correlations between temperatures and visual and infrared properties of clouds in Jupiter: 1984-1991. *Bull. Amer. Astron. Soc.* **23**, 1136.

Orton, G., J. Friedson, T. Thaller, D. Gezari., F. Varosi, C. Barnet, P. Drossart, J. Lecacheux, P. Laques, F. Colas, J. Caldwell 1991. Enhanced stratospheric temperatures over Saturn's great equatorial storm of 1990. *Bull. Amer. Astron. Soc.* **23**, 1149.

Orton, G. S., J. H. Lacy, J. Achtermann, P. Parmar, W. E. Blass. 1992. Thermal spectroscopy of Neptune: the stratospheric temperature, hydrocarbon abundances, and isotopic ratios. Submitted to *Icarus*.

Radar Investigation of Asteroids and Planetary Satellites

Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109

Steven J. Ostro

Strategy

Radar reconnaissance of near-Earth asteroids, mainbelt asteroids, the Galilean satellites, the Martian satellites, and large Saturnian satellites, using the Arecibo 13-cm and the Goldstone 3.5-cm systems. Measurements of echo strength, polarization, and delay/doppler distribution of echo power provide information about dimensions, spin vector, large-scale topography, cm-to-m-scale morphology, and surface bulk density. The observations also yield refined estimates of target orbital elements.

Accomplishments

Radar signatures have been measured for 37 mainbelt asteroids (MBAs) and 29 near-Earth asteroids (NEAs) since this task began ten years ago. A radar movie of the NEA 4179 Castalia (1989 PB) shows it to consist of two kilometer-sized lobes in contact. The NEA 1986 DA is significantly more reflective than other radar-detected asteroids; it may be a piece of NiFe metal derived from the interior of a much larger object that melted, differentiated, cooled, and subsequently was disrupted in a catastrophic collision. Phobos' 3.5- and 13-cm echoes reveal surface characteristics very different from those of most near-Earth asteroids, but similar to those of the largest C-class asteroids. Deimos is no more than half as radar-bright as Phobos; its regolith probably is extremely tenuous. The radar signatures of Europa, Ganymede, and Callisto have been measured at 3.5, 13, and 70 cm and are extremely unusual at all three wavelengths. Doppler residuals measured during 1987-91 show the Callisto ephemerides to have a longitude error greater than 100 km. Radar spectra for several large MBAs (e.g., 12 Victoria) show evidence for prominent concavities in their gross shapes. All delay-doppler asteroid radar astrometry obtained during 1980-1990 has been published, along with refined orbital estimates and disc-integrated radar properties for all astrometrically observed targets. 1991 astrometry included coarse ranging to 324 Bamberga and 200-nanosecond (30-meter) ranging to 1991 JX. In the first Goldstone-VLA observations of asteroids, we (a team led by I. de Pater) detected Bamberga, 7 Iris, and 1991 EE.

Anticipated Accomplishments

- i) Publication of results of 1987-92 Arecibo/Goldstone observations of the icy Galilean Satellites.
- ii) First Galilean Satellites ranging observations.
- iii) Measurement of the 3.5-cm signatures of Io and 4 Vesta.
- iv) High-resolution imaging, with ~10,000 on-target pixels, of the very large NEA 4179 Toutatis during its extremely close approach to Earth in December 1992.

Publications

Ostro, S. J., D. B. Campbell, J. F. Chandler, A. A. Hine, R. S. Hudson, K. D. Rosema, and I. I. Shapiro (1991). Asteroid 1986 DA: Radar Evidence for a Metallic Composition. *Science* **252**, 1399-1404.

Ostro, S. J., D. B. Campbell, J. F. Chandler, I. I. Shapiro, A. A. Hine, R. Velez, R. F. Jurgens, K. D. Rosema, R. Winkler, and D. K. Yeomans (1991). Asteroid Radar Astrometry. *Astron. J.* **102**, 1490-1502.

Ostro, S. J. (1991). Radar Reconnaissance of Near-Earth Asteroids. In *International Symposium on Radars and Lidars in Earth and Planetary Sciences* (T. Guyenne and J. J. Hunt, ed.), ESA **SP-328**, ESA Publications Division, ESTEC, Noordwijk, The Netherlands, pp.9-13 (1991).

Yeomans, D. K., P. W. Chodas, M. S. Keesey, S. J. Ostro, J. F. Chandler, and I. I. Shapiro (1992). Asteroid and Comet Orbits Using Radar Data. *Astron. J.* **103**, 303-317.

Spectroscopic Observations of Outer Planets

University of Hawaii
Honolulu, Hawaii 96822

T. C. Owen

Strategy

This program concentrates on the study of planetary and satellite atmospheres by means of Earth-based spectroscopic observations.

Progress and Accomplishments

VENUS: In November of 1989, we successfully observed HDO in the atmosphere of Venus by recording the spectrum of thermal emission from the dark side of the planet in the 2.35 mm atmospheric "window". We found an enrichment of $D/H = 120 \pm 40$ times the telluric value, confirming earlier measurements of a 100x enrichment by Pioneer Venus mass spectrometers. To determine what this means for the history of water on Venus, we need to know the current global water abundance. We obtained new observations of the dark side of Venus in 1991 that are currently being analyzed in order to derive this important quantity.

JUPITER: With Richard Baron, Owen obtained images of the H3+ aurora at the poles of Jupiter at several different wavelengths. Highlights include the first definition of the spatial extent of the aurora and a discovery of rapid time variations. Caitlin Griffith, Owen's graduate student at Stony Brook, completed her analysis of Voyager spectra of the Great Red Spot. The main results are an absence of any detectable enhancement of PH₃ within or above the GRS, and a puzzling depletion of NH₃ within the GRS. This research was part of Griffith's PhD dissertation (see section: TITAN below).

SATURN: Baron and Owen detected thermal hot spots on Saturn for the first time at 4.9 micron. These emission regions exhibit strong limb darkening, unlike comparable features on Jupiter. They offer an interesting opportunity for future probing of the deep atmosphere of Saturn.

TITAN: Griffith and Owen published an analysis of the near IR spectrum of Titan that demonstrated the existence of windows in Titan's spectrum at 1.3, 1.6 and 2.0 micron. It may be possible to sense the satellite's surface through these windows. If so, the most likely candidates for the major surface material is dirty water ice. (This was also part of Griffith's PhD Dissertation.)

NEPTUNE: We used the JCMT and CSO radio telescopes on Mauna Kea to detect HCN and CO in Neptune's stratosphere. CO is well mixed in the atmosphere, while

HCN is confined to the stratosphere. The most plausible interpretation is that CO is mixed upward into the stratosphere from the deep interior, along with N₂. N₂ is then dissociated to combine with CH from methane to make HCN. The lack of a strong internal heat source on Uranus would lead to reduced vertical convection, which may explain our inability to detect these two molecules in that planet's stratosphere.

TRITON: Tom Geballe obtained a new spectrum of Triton in the 1.4 -- 2.5 micron region at Owen's request, and this is being analyzed by Owen, Dale Cruikshank and Catherine de Bergh. We have so far discovered CO and CO₂ absorptions on Triton's surface, and found that the putative N₂ absorption at 2.15 micron is more complex than expected.

Anticipated Accomplishments

JUPITER: We have obtained new spectra of Jupiter in March 1992 near 4 micron with the FTS and the CFHT at Mauna Kea. We are analyzing these spectra to search for evidence of trace constituents in Jupiter's atmosphere.

SATURN: We are proposing to follow up our discovery of 4.9 micron hot spots by obtaining spectra in this region to look for trace constituents in Saturn's atmosphere.

TITAN: We will take advantage of the improved angular resolution at the IRTF to try to obtain images of Titan's lower atmosphere and surface through the windows in the near IR spectrum.

NEPTUNE: We have new observations of the sub-mm spectrum with the JCMT and CSO that will be used to improve current models for Neptune's atmosphere.

TRITON AND PLUTO: New observations of both objects with CGS4 and of Pluto with CSHELL are scheduled for May. The resulting spectra will be used to test for the presence of N₂, CO, and CO₂, on Pluto, and to search for evidence of organic compounds on both Triton and Pluto. The CSHELL spectra of Pluto should permit a determination of the atmospheric methane abundance.

Publications

"Deuterium on Venus: Observations from Earth" C. de Bergh, B. Bezard, T. Owen, D. Crisp, J. P. Maillard, and B. L. Lutz. *Science* **251**, 547-549 (1991).

"Noble Gases in Terrestrial Planets: Evidence for Cometary Impacts?" T. Owen, A. Bar-Nun and Idit Kleinfeld, in *COMETS IN THE POST-HALLEY ERA*, ed. R. Newburn, Jr., M. Neugebauer, and J. Rahe (Dordrecht: Kluwer) pp **429-437** (1991).

"Spectroscopy and Chemistry of the Atmosphere of Uranus" B. Fegley, Jr., D. Gautier, T. Owen and R. G. Prinn. In *URANUS*, ed. J. Bergstralh, E. D. Miner and M. S. Matthews (Tucson: University of Arizona Press) pp **147-203** (1991).

"Titan's Surface and Troposphere, Investigated with Ground-Based, Near Infrared Observations" C. A. Griffith, T. Owen, and R. Wagener. *Icarus* **93**, 362-378 (1991).

"Imaging Jupiter's Aurorae from H3+ Emissions in the 3-4 mm Band" R. Baron, R. D. Joseph, T. Owen, J. Tennyson, S. Miller, and G. E. Ballester. *Nature* **353**, 539-542 (1992).

Exospheres of the Moon and Mercury

NASA Johnson Space Center
Houston, Texas 77058

Andrew Potter
Thomas Morgan

Strategy

The sodium and potassium atmospheres of Mercury and the Moon are mapped using spectroscopic measurements of resonance scattered sunlight. The objective is to define the sources and sinks for these atmospheric constituents, and in so doing, provide a better understanding of atmospheric processes on these bodies, which are unique, in that their atmospheres consist solely of an exosphere with the planetary surface at its base.

Progress and Accomplishments

Same-day images of potassium and sodium emission for Mercury were obtained for four consecutive days near first quarter of the planet. The surprising result is that sodium and potassium do not seem to be closely coupled. Differences were expected, due to the different volatilities, g-factors, and photoionization thresholds of the two elements, but not as large as were observed. Detailed criticisms were published of the concept that diffusion from subsurface fractures could explain the origin of potassium vapor observed on Mercury.

Resonance emission from the sodium exosphere was measured up to about 1500 km above the lunar surface at various positions around the Moon, and at different lunar phases. Effective temperatures of approximately 1000 K were determined from the data. The fact that the sodium density and distribution changed little when the Moon entered the Earth's magnetotail, where it was shielded from the solar wind, suggests that solar photon radiation plays a major role in maintaining the density and temperature of the sodium.

Anticipated Accomplishments

We plan to continue efforts to collect same-day potassium and sodium distributions on Mercury. We hope to build a reducing lens for the McMath telescope that will speed up the image data collection ten-fold, allowing us to explore the possibility of rapid (hourly) changes in these atmospheric components, and will also improve the quality of the data.

We plan to use the 40-cm coronagraph at the National Solar Observatory, Sunspot to map the complete sodium distribution around the Moon. Point-source measurements that we have used in the past are impossibly slow for mapping the entire exosphere before it changes. A complete map of the exosphere should allow development of improved theory for the origin of this exosphere. We also plan to initiate new measurements of the dust layer above the lunar terminator. We have recently found evidence for the existence of this layer.

In addition, we plan to initiate new mapping measurements of Mercury in reflected and emitted light, using the protoCAM at the IRTF, in order to learn something about the thermal properties of the Mercury surface.

Publications

Killen, R. M. , A. E. Potter, and T. H. Morgan, (1991), "Detecting Potassium on Mercury", *Science*, **252** 974-975.

Morgan, T. H. and D. E. Shemansky, (1991), "Limits to the Lunar Atmosphere", *J. Geophys. Res.* **96**, 1351-1367.

Morgan, T.H. and S. A. Stern, (1991) "Revived Interest in the Lunar Atmosphere" EOS, Transactions, *Am. Geophys. Union*, **72** 225

Potter, A. E. and T. H. Morgan, (1991), "Observations of the Lunar Sodium Exosphere". *Geophys. Res. Lett.* **18**, 2089-2092.

Shemansky D. E. , and Morgan, T. H. (1991), "Source Processes for the Alkali Metals in Mercury", *Geophys. Res. Lett.* **18**, 1659-1662.

Ground-Based Cometary Studies

Lowell Observatory
1400 W. Mars Hill Rd.
Flagstaff, AZ 86001

David G. Schleicher

Strategy

In this grant we seek to understand the physical properties of comets by applying a wide variety of observational techniques. We particularly emphasize simultaneous or coordinated observations in different spectral regions (e.g. visible and thermal I.R. or visible and far U.V.) or with different instrumentation (imaging, spectroscopy, photometry). We aim to (1) measure the basic properties of cometary nuclei by studying comets whose comae are so anemic that the signal from the nucleus can be extracted, (2) investigate the group characteristics of comets by narrowband photometry applied uniformly to a large sample of comets, (3) understand the detailed physics and chemistry occurring in cometary comae through wide-field CCD imaging using narrow filters and through long-slit CCD spectroscopy, and (4) investigate the rotational states of comets through time-resolution photometry.

Progress and Accomplishments

In the past year we have completed a major observing campaign of Comet Levy (1990c) along with several other investigations. Photometric observations of Comet Levy began in early July 1990 and continued until May 1991. These data indicated that most molecular species had production rates twice as large before perihelion as after; however, the OH production rate asymmetry was nearly double that measured for the other species, and the peak in the OH production occurred more than a month before other species. Time-resolution monitoring of Levy in late August revealed periodic variations with a 19 hr period. Levy is the first long-period comet in which rotational variations have been observed using photometric techniques. The Levy results were published in *Icarus*. An investigation of the spatial distribution of grains in the comae of 14 comets has been completed. Clear evidence of grain "fading," possibly due to sublimation, was found for the majority of the comets. This work has been accepted for publication in *The Astronomical Journal*. Photometry of Comet P/Wolf-Harrington obtained on three nights confirmed the apparently anomalous molecular abundances previously indicated by a single observation made during the comet's 1984 apparition. Depletions of C₂, C₃, and NH with respect to OH and CN are substantially greater than those exhibited by any of the other 79 comets in our data base. Analysis of the data base has progressed - preliminary taxonomic classifications for comets have been determined and evidence for evolutionary effects has been found. To assist in the planning of future spacecraft missions, complete observational results for nine comets previously suggested as potential targets have been submitted to

Icarus. One of the nine comets - P/Grigg-Skjellerup - will be observed by the Giotto spacecraft in July 1992.

Anticipated Accomplishments

In the next year, emphasis in this research program will be given to the continued analysis and the publication of our data set on Comet P/Halley, and of our total data base of comet photometry. Previously obtained CCD observations of several comets will be used to constrain the lifetimes of molecular species and to further investigate the properties of grains in cometary comae. Finally, observations of newly discovered comets will be undertaken as circumstances warrant.

Publications

Schleicher, D. G., and Bus, S. J. (1991) Comet P/Halley's Periodic Brightness Variations in 1910. *Astronomical Journal* **101**, 706-712.

Bus, S. J., A'Hearn, M. F., Schleicher, D. G., and
Bowell, E. (1991) Detection of CN Emission from
(2060) Chiron. *Science* **251**, 774-777.

Schleicher, D. G., Millis, R. L., Osip, D. J., and
Birch, P. V. (1991) Comet Levy (1990c): Ground-
based Photometric Results. *Icarus* **94**, 511-523.

Baum, W. A., Kreidl, T. J., and Schleicher, D. G.
(1992) Cometary Grains. *Astronomical Journal*, in
press.

Imaging and Spectroscopy of Io's Torus and Atmosphere

University of Colorado

Nicholas M. Schneider

Strategy

The focus of our research are the complex interactions between Jupiter's magnetosphere and Io's atmosphere. Our group specializes in innovative observations of the Io/Jupiter system. Imaging observations provide 'movies' of the features in Io's escaping atmosphere and in the ring of sulfur and oxygen ions which encircles Jupiter. Spectroscopic observations provide essential information on composition, and can also be used to measure velocities of the constituents down to a few hundred meters/sec.

Progress and Accomplishments

In the past year we have demonstrated that molecular chemistry is unexpectedly important in Io's atmosphere and in the torus. Our proposed molecular processes explain the 'fast sodium jets' which have defied explanation up to this point. This conclusion is significant because it was previously thought that molecules would be destroyed so rapidly that they would play no significant part in Io's atmosphere or the torus. These same observations are also surprisingly useful in probing the precise manner in which plasma is picked up near Io, and we have reached the conclusion that the atmosphere/plasma interaction slows the flow around Io to less than a third of its unperturbed value.

Anticipated Accomplishments

Images of the torus provide a wealth of information on plasma temperature(s), densities, composition, and the position of prominent features. With these measurements we can map the structure of the plasma torus. We expect to publish results on the 'warping' of the plasma plane, and observed local time and magnetic longitude variabilities of the torus. We are also working to tie our 'variability timeline' to changing volcanic activity on Io and auroral activity on Jupiter.

We have reduced the largest, highest-quality data-set of spectroscopic observations of the sodium cloud. These yield high resolution velocity maps; in the coming year we will use them to constrain models of atmospheric escape from Io.

In addition, we will extend our work on molecular escape from Io, and develop a model of plasma flow past Io which is consistent with our data.

Publications

N.M. Schneider, J.T. Trauger, J.K. Wilson, D.I. Brown, R.W. Evans, D.E. Shemansky:
"Molecular Origin of Io's Fast Sodium", *Sci* **253**,
1394 (1991).

D.M. Hunten, W.K. Wells, R.A. Brown, N.M. Schneider and R.L. Hilliard, "A Cassegrain Echelle Spectrograph", *PASP*, **103**, 1187-1192.

N.M. Schneider, J.T. Trauger, "Io Torus Double Feature", videotape distributed to the Io community.

Radar Studies in the Solar System

Smithsonian Institution
Astrophysical Observatory

Irwin I. Shapiro

Strategy

We are engaged in a study of the solar system by means of ground-based radar. We have concentrated on (i) developing the ephemerides needed to acquire radar data at Arecibo Observatory and (ii) analyzing the resultant data to: test fundamental laws of gravitation; determine the size, shape, topography, and spin vectors of the targets; and study the surface properties of these objects, through their scattering law and polarization characteristics.

Progress and Accomplishments

We are actively engaged in radar observations of asteroids and comets, both as systematically planned targets and as "targets of opportunity." During the past year, we attempted observations of three newly-discovered asteroids (two within a few weeks of discovery) as well as five planned asteroids. One of the attempts (1991 VG) failed because the target's radar cross-section was too low, but the other attempts at observing new targets were highly successful. These observations took advantage of ephemeris refinements based on the available optical data beforehand and on the preliminary radar data during the observing run. The results are still being analyzed. The observing program also covered two of the four Galilean satellites of Jupiter. In addition, progress was made in our ongoing effort to obtain "closure point" observations of Mercury, both at Arecibo and at the Goldstone radar operated by JPL. Finally, we have continued the analysis of radar data and prepared articles for publication in collaboration with our colleagues. Three papers were published, and two more are in preparation, one on the rotation of Venus and one on the Galilean satellites.

Anticipated Accomplishments

We plan to continue our activities in this field, both by obtaining radar observations of asteroids, comets, planets, and satellites and by analyzing the data. We plan to refine the spin vector of Venus on the basis of recently acquired data; the result could be important in the interpretation of results from the Magellan mission.

Publications

Ostro, S.J., Campbell, D.B., Chandler, J.F., Hine, A.A., Hudson, R.S., Rosema, K.D., and Shapiro, I.I., *Science* **252**, 1399, 1991.

Ostro, S.J., Campbell, D.B., Chandler, J.F., Shapiro, I.I., Hine, A.A., Velez, R., Jurgens, R.F., Rosema,

K.D., Winkler, R., and Yeomans, D.K., *Astron. J* **102**, 1490, 1991.

Yeomans, D.K., Chodas, P.W., Keesey, M.S., Ostro, S.J., Chandler, J.F., and Shapiro, I.I., *Astron. J* **103**, 303, 1992.

Radio Interferometric Studies of Comets

Department of Astronomy
University of Illinois

Lewis E. Snyder (P.I.)
Patrick Palmer, and Imke de Pater (Co-I)

Strategy

Spectral line radio interferometry is used to study the composition, velocity distribution, maser excitation, and plasma interactions of cometary gas. In the past, we mapped OH emission and detected formaldehyde emission from several comets, including Comet Halley. Our newest approach is to conduct bistatic radar observations of asteroids in order to build the framework for future interferometric observations of cometary nuclei. Radar alone provides excellent information about the position and motion of the objects along the line of sight; by receiving the return with the VLA, we determine the position in the plane of the sky and expect to resolve details of the objects as well.

Progress and Accomplishments

On September 9, 1991, I. de Pater, P. Palmer, S. Ostro, D. Yeomans, and L. E. Snyder used the VLA to receive radar returns from the asteroids 1991EE and Bamberga. The X-band radar signal was transmitted by the 70m Deep Space Network antenna at Goldstone, CA. On September 13, Bamberga and 1991EE were reobserved, and on September 16., Iris was observed. Only the data for September 9 have been studied carefully yet, as software development has been going on to correct the data for the phase errors caused by the asteroids being in the near field of the VLA A-array. Bamberga is a relatively large asteroid (diameter = 242 km) which was about 0.8 AU from the Earth when observed on September 9. Therefore the near-field effect, although important, does not completely blur out images. To date, the most fully processed image uses all of the September 9 data and has 0.49×0.45 arcseconds resolution. The data clearly show that the asteroid is displaced 1.99 ± 0.06 arcseconds East and 0.65 ± 0.02 arcseconds North from the ephemeris position derived from optical observations made between 1905 and 1985. The apparent size of the object is 0.39×0.23 arcseconds (position angle 152 degrees). A 240 km diameter disk at the distance of Bamberga during these observations would subtend 0.41 arcseconds. Thus within the uncertainties of the diameter measurement, the radar measurements agree with the diameter deduced from optical studies. This is consistent with the expectation that an object of this size will be very rough so that specular reflection will not give a bright point at the sub-radar point on the disk (as is seen in planetary observations).

Anticipated Accomplishments

As new comets appear, we plan to continue our VLA spectral line observations and eventually perform more bistatic radar observations. This summer, we plan to conduct interferometric observations of Comet Shoemaker-Levy in both OH and formaldehyde.

The data for asteroid 1991EE still resist processing. A severe phase wind is seen which was originally attributed to it being in the near field of the VLA. However, additional software development suggests that this is not the only cause. Software development will continue, and tests using the VLA itself will be carried out this summer by observing a TDRS satellite in the C- array (which will provide about the same value of the nearness parameters as 1991EE did in the A-array). In this way any problems involving the VLA hardware or on-line control system which affect the study of nearby objects can be investigated.

Publications

Snyder, L. E., Palmer, P., and de Pater, I., 1992, "Comet Halley and Interstellar Chemistry", in *Chemistry and Spectroscopy of Interstellar Molecules*, ed. N. Kaifu (University of Tokyo Press).

Snyder, L. E., 1992, "Cometary Molecules", in *The Astrochemistry of Cosmic Phenomena*, ed. P. D. Singh (Dordrecht: Kluwer), in press.

Palmer, P., Snyder, L. E., and de Pater, I., 1992, "Radio Interferometric Observations of Cometary Molecules", in *The Astrochemistry of Cosmic Phenomena*, ed. P. D. Singh (Dordrecht: Kluwer), in press.

Monitoring Io's Volcanos with Infrared Imaging

Lowell Observatory
1400 W. Mars Hill Rd.
Flagstaff, AZ 86001

John R. Spencer

Strategy

Obtain information with high spatial and temporal resolution on Io's volcanic activity using infrared observations of its volcanic thermal emission. The two main techniques used are infrared photometry of occultations of Io by Europa in 1991, and disk-resolved imaging of Io near and during eclipse and occultation by Jupiter over a 3-year period.

Progress and Accomplishments

We observed 4 occultations of Io by Europa between January and March 1991, using the United Kingdom Infrared Telescope on Mauna Kea, at either 3.4 or 4.8 microns wavelength. In two of the events Europa occulted the hot spot Pele, showing that its position was within about 25 km of the location seen by Voyager in 1979. In one event the major hot spot Loki was also occulted, and the 20 second duration of the occultation provided spatial resolution within the hot spot.

Since October 1990 we have observed 19 eclipses and occultations of Io by Jupiter using a 1-5 micron infrared camera at the NASA Infrared Telescope Facility on Mauna Kea. We usually resolved Io's 1 arcsecond disk, with a typical angular resolution of 0.5 arcseconds or better. At least two hotspots could normally be resolved at 3.5 - 4.8 microns (sometimes 4 or 5), allowing determination of the location, power, and temperature of each. Even higher spatial resolution, in one dimension and at one wavelength, was usually attained from photometry of the occultations of Io by Jupiter. These observations document a major outburst of Loki between December and April 1991, and its low level of activity (down by a factor of 10 at 3.8 microns) before and ever since that event. They also show very constant activity at the hot spot "Kanehekili", the second brightest hot spot on the Jupiter-facing hemisphere of Io, between December 1989 and April 1991, but a drop in activity by October 1992. Some smaller spots show stability over a year, while others appear for only a few weeks.

Disk-integrated observations of Io in Jupiter eclipse at 2.2 and 1.6 microns allowed the temperature of the hottest parts of the hot spots to be measured. These observations show that several square km at about 800 K, much too hot for liquid sulfur, are usually present on Io's surface. Landsat observations of thermal emission at the same wavelengths from the andesitic Andean volcano Lascar have roughly comparable color temperatures, showing that the short-wavelength Io emission is at least consistent with silicate volcanism.

Anticipated Accomplishments

We will continue frequent observations of Io eclipses and occultations by Jupiter, including observations from 1.6 - 2.5 microns with an Ohio State infrared camera at Lowell Observatory. I am developing improved techniques for reduction of the large amount of data already gathered, and intend to concentrate also on systematic reduction and publication of the existing data. The results of the 1991 Europa occultations will be submitted for publication shortly, once accurate ephemerides for Io and Europa are available.

Publications

No refereed publications during this time period.

New Directions in Cometary Spectroscopy

Astronomy Department
University of California
Berkeley, CA

Hyron Spinrad

Strategy

Quantitative information on the Near-nucleus velocity fields of cometary neutrals and ions, and data on their distribution further out into the comet comae are necessary to build realistic models of the outflow of matter from the irregular cometary nucleus. We are beginning observational programs to shed light on both questions.

Progress and Accomplishments

We have obtained high spectral/spatial-resolution echellograms of the $H\infty$ line near the nuclei of Comets Austin and Levy. To our surprise, these spectra show a marked dominance of very low-velocity H ejecta, presumably the collisionally thermalized component of the photodissociation products of H_2O and H. We are currently modeling the gas outflow to compare with our velocity-sensitive measures.

We have also carried out 2-D surface photometry (in C_2 , CN, [OI]) for two bright comets; the [OI] radical gradient in Comet Austin seems unusually steep.

Anticipated Accomplishments

Among several spectroscopic programs, we plan to measure the velocity field of H_2O^+ ions in near-tail/comae with the echelle system.

Publications

"Systematic Displacements Between Gas and Dust in the Sunward Fans of Two Low-Activity Comets", H. Spinrad, *Astron. J.* **102**, 1207, 1991.

"High-Resolution Observations of the Spatial and Velocity Distribution of Cometary Hydrogen", M. E. Brown and H. Spinrad, 1992, in *Asteroids, Comets, Meteors III*, in press.

Monitoring and Modeling of the Pluto-Charon System

Institute for Astronomy
University of Hawaii
Honolulu, HI 96820

David J. Tholen

Strategy

The main focus of this research is to continue the final reduction and analysis of photometric data acquired during the Pluto-Charon mutual event season, which extended from 1984 December through 1990 October. Over fifty events were observed, most with the University of Hawaii 2.24-m telescope on Mauna Kea, thus we have a large, uniform, and high signal-to-noise ratio set of data spanning the full range of geometries produced by the system during the eclipse years. Our goal is to determine the most reliable values for the orbital and physical parameters of the system, thereby providing an initial characterization of the most remote of the planets and place some constraints on the conditions in the solar nebula out of which these objects formed.

Previous models that we used to bootstrap our way through the season made several simplifying assumptions to permit analytical methods to be used instead of more computationally intensive numerical methods. These models have been unable to completely satisfy the data, however, as evidenced by the fact that the mean residual exceeds the mean error bar of the data by a factor of about 1.3. This excess is due mainly to the simplifying assumptions, but the uncertainties in the data themselves are probably slightly underestimated as well, due to exclusion of scintillation noise in the calculation of the uncertainty (which can be non-negligible at the higher airmasses) and the preliminary values of the comparison star magnitudes that had been utilized.

Anticipated Accomplishments

We plan to first reduce all available comparison star data and examine the data for any signs of variability at the millimagnitude level. Once final magnitudes and colors have been adopted (as a function of time, if necessary), final reduced magnitudes for the Pluto-Charon system can be computed. With the complete data set in hand, new fits will be made to these data using models that include a variety of effects previously ignored, such as the finite width of the penumbral shadow cast by one body on the other, the location of the defect of illumination, differences in the phase functions of the two objects' surfaces, the changing mean color of the system during an event, and so on.

New photometric observations of the system will also be made to extend the light-curve of the system to more northerly sub-solar and sub-Earth latitudes. The system has faded by over 0.25 mag since the onset of photoelectric brightness measurements in the mid 1950s, and the rotational light-curve amplitude has increased from about 0.1 mag

to about 0.3 mag. Both effects are believed to be due to the albedo distribution of the surface coupled with the changing aspect of the system as it advances in its orbit around the Sun. Knowledge of the albedo distribution is essential for determining the individual densities of the two bodies via the measurement of the barycentric wobble, given the likely offset between the geometric centers of the disks and the photocenters (note that Pluto's large scale surface contrast is second only to Iapetus in the Solar System). Continued observation of the system's light behavior as the solstice is approached will provide a much better constraint on the albedo distribution in the northern polar regions, and should also help determine whether the albedo distribution is temporally variable.

Observations of Spacecraft Targets, Unusual Objects, and Other Targets of Opportunity

Institute for Astronomy
University of Hawaii
Honolulu, HI 96822

David J. Tholen

Strategy

Part of this project is to provide supporting photometric and astrometric data for asteroids and comets that are or may be the targets of spacecraft flybys or rendezvous. The reflected light photometric data are used to derive the rotation rate, phase function, shape estimate, orientation of spin axis, and compositional information. When combined with radiometric measurements of the thermal emission, the effective diameter and albedo can be extracted as well. The astrometric data are used to improve the orbit of the object, knowledge of which is essential for successful navigation of the spacecraft to the object.

Progress and Accomplishments

Although the photometric data are acquired using standard techniques, the astrometric data are obtained using a novel method involving the measurement of the angular offset from one or more nearby astrometric reference stars using the encoders on a telescope's polar and declination axes. This technique was pioneered by the investigator in 1981 and over the years has proven capable of subarcsecond accuracy, if the appropriate care is taken when the observations are made, and if the necessary differential corrections for precession, nutation, aberration, and refraction are applied.

Recent efforts have been directed toward the two asteroids that are targets of the Galileo spacecraft, namely 951 Gaspra (encountered on 1991 October 29) and 243 Ida (to be encountered in 1993 August). Simultaneous reflected light and thermal emission observations of 951 Gaspra were obtained on 1991 May 18 and of 243 Ida on 1992 January 22. When combined with light-curve observations at other aspects, the former observations suggest a shape for Gaspra of about 16 by 11 by 11 km and a visual geometric albedo of 0.22. The reductions of the Ida data are currently underway. Observations of 4660 Nereus, the leading candidate for the NEAR mission, are planned for later in 1992, as well as the 1993 opposition.

Anticipated Accomplishments

The other major part of this project is a photometric survey of planet crossing asteroids. From these observations, we hope to find additional parent bodies for

various terrestrial meteorite classes, especially the ordinary chondrites; to better constrain the fraction of the planet crossing object population that is due to extinct or inactive comets; to find objects with water of hydration in low delta-v orbits; to determine the source region in the main belt for the planet crossing asteroid population; and to compare the distribution of physical properties, such as taxonomic classification and rotation states, with the main belt.

Publications

Britt, D. T., D. J. Tholen, J. F. Bell, and C. M. Pieters 1992. A review of asteroid and meteorite spectral relationships: Classification by principal components analysis. *Icarus* (submitted).

Buie, M. W., D. J. Tholen, and K. Horne 1992. Albedo maps of Pluto and Charon: Initial mutual event results. *Icarus* (in press).

Cruikshank, D. P., W. K. Hartmann, D. J. Tholen, L. J. Allamandola, R. H. Brown, and C. N. Matthews 1991. Solid C=N bearing material on outer solar system bodies. *Icarus* **94**, 345-353.

Cruikshank, D. P., D. J. Tholen, W. K. Hartmann, J. F. Bell, and R. H. Brown 1991. Three basaltic Earth-approaching asteroids and the source of the basaltic meteorites. *Icarus* **89**, 1-13.

Goldader, J. D., D. J. Tholen, D. P. Cruikshank, and W. K. Hartmann 1991. Galileo support observations of asteroid 951 Gaspra. *Astron. J.* **102**, 1503-1509.

Magnusson, P., M. A. Barucci, R. P. Binzel, C. Blanco, M. Di Martino, J. D. Goldader, M. Gonano-Beurer, A. W. Harris, T. Michalowski, S. Mottola, D. J. Tholen, and W. Wisniewski 1992. Asteroid 951 Gaspra: Pre-Galileo physical model. *Icarus* (in press).

Mueller, B. E. A., D. J. Tholen, W. K. Hartmann, and D. P. Cruikshank 1992. Colorimetry of 1992 AD. *Icarus* (in press).

Ground-Based Studies of the Outer Planets

University of Texas at Austin

L. Trafton (PI)

Strategy

This program conducts ground-based studies of outer solar system planets and satellites with emphasis on spectroscopy of atmospheres and atmospheric phenomena. Investigations of composition, physical characteristics and changes in outer solar system bodies are conducted primarily using the facilities of McDonald Observatory.

Progress and Accomplishments

During 1991, a successful program of monitoring Io's 2.125 micron feature during the series of mutual eclipses and occultations between Io and other Galilean satellites was carried out. The object was to determine its distribution over Io's disk. This provides information on the nature and state of the source material. Preliminary eclipse results were reported at the spring meeting of the AGU and at the AAS/DPS meeting in Palo Alto. The source material was found not to be frozen out over Io's poles, but nearly uniformly spread over the disk, with some local concentration in low latitude regions. This is consistent with the proposed CO₂ clusters if local regions of high albedo are dispersed over the entire disk. High resolution spectra of this feature were obtained at the KPNO 4m FTS to obtain profile shape and width as a further aid in identification. Although these were obtained through variable clouds, the results provided accurate values of centroid wavelength, equivalent width, intrinsic full width at half maximum, and overall shape. Fine structure characteristic of a gas was not apparent. We discovered a second feature in Io's K-band spectrum, located at 1.982 microns. It also is narrow and about the same strength as the 2.125 micron feature. It may belong to the same class of source material. In collaboration with J. K. G. Watson at the Herzberg Institute for Astrophysics, we have analyzed our spectra showing a global scale infrared emission on Jupiter in terms of excitation of the H₂ dimer.

Anticipated Accomplishments

In 1992, we will continue our spectrographic studies of Io's K-band absorptions and of Jupiter's aurorae. We will complete the reductions and analysis of the occultation data and compare the results with the eclipse data. We will also reduce CCD data obtained during 1991 of Io's Na and K emissions during the eclipse of Io by another satellite to study the distribution of these species near Io's polar regions. We will continue to observe Jupiter's aurorae from McDonald, mapping out the emissions and monitoring for global scale activity. We will also observe the aurora from the UKIRT using the CGS4 longslit spectrograph in the K, L', and L bands. We will continue to search for

aurorae on other outer planets. Finally, we will continue our Pluto and Triton monitoring programs.

Publications

"A New Class of Absorption Feature in Io's Near-Infrared Spectrum", L. M. Trafton, D. F. Lester, T. F. Ramseyer, F. Salama, S. A. Sanford, and L. J. Allamandola, *Icarus* **89**, 264-27; 19916.

"A Search for Pluto's Extended Atmosphere", J. T. Clarke, S. Alan Stern, and L. M. Trafton, *Icarus*, in press.

"Evidence of Global-Scale Auroral Activity on Jupiter: Proposed Identification of Jovian Auroral Dimer H₂ Emission", L. M. Trafton and J. K. G. Watson, *Astrophys. J.*, in press.

"First Results from the GHRS: Resolved Velocity and Density Structure in the "Pictoris Circumstellar Gas", A. Boggess, F. C. Bruhweiler, C. A. Grady, D. C. Ebbets, Y. Kondo, L. M. Trafton, J. C. Brandt, and S. R. Heap, *Astrophys. J. (Letters)*, **377**, L49-L52; 1991.

"Laboratory Studies of the Newly Discovered Infrared Band at 4705.2 cm⁻¹ (2.1253 μ m) in the Spectrum of Io: The Tentative Identification of CO₂", S. A. Sanford, F. Salama, L. J. Allamandola, L. M. Trafton, D. F. Lester, and T. F. Ramseyer, *Icarus*, **91**, 125-144; 1991.

"Rotationally Resolved Midultraviolet Studies of Triton and Pluto/Charon System I: IUE Results", S. A. Stern, N. Brosch, E. S. Barker, and G. R. Gladstone, *Icarus*, **92**, 332; 1991.

"Steps Toward Determination of the Size and Structure of the Broad-Line Region in Active Galactic Nuclei, II", B. M. Peterson, ..., E. S. Barker, ..., *Ap. J.*, **368**; 1991.

"The Development of the CO+ Coma of Comet Schwassmann-Wachmann 1", A. L. Cochran, W. D. Cochran, E. S. Barker, and A. D. Storrs, *Icarus*, **93**, 179; 1991.

Compositional Studies of Primitive Asteroids

Space Science Branch
Solar System Exploration Division
NASA Johnson Space Center
Houston, Texas 77058

Faith Vilas

Strategy

The aqueous alteration history in the solar system will be studied through acquiring narrowband reflectance spectra in the blue-UV through the near-infrared (0.4 - 1.0 μm) spectral region and analyzing these spectra for information about iron oxides in phyllosilicates identified in the CM and CI carbonaceous chondrites. Emphasis will be on the main-belt and Cybele primitive asteroids, as these asteroids show spectral diversity and are also spectral analogues for known meteorite samples.

Progress and Accomplishments

During 1991, additional narrowband reflectance spectra of main-belt C-class (and some sub-classes) asteroids and some outer-belt asteroids were acquired. The majority of main-belt C-class asteroid spectra show an absorption feature centered at 0.7 μm attributed to Fe^{2+} - Fe^{3+} charge transfer in iron oxides present in phyllosilicates. Some of the spectra show absorption features in a bi-modal pattern found also in some carbonaceous chondrite spectra. Spectra taken in the blue-UV region showed no evidence of the 0.4- μm Soret band indicative of porphyrins, but did show a small absorption band at 0.43 μm .

Anticipated Accomplishments

The data base of narrowband reflectance spectra of primitive asteroids will continue to be enlarged, continuing to emphasize the main-belt and Cybele primitive asteroids, and extending the coverage to shorter wavelengths. The new spectral pattern of bi-modal absorption features in the visible and near-infrared will be studied. Detail in the spectra of these asteroids will reveal more of the history of aqueous alteration in the solar system.

Publications

Vilas, F. and McFadden, L. A. (1992). "CCD Reflectance Spectra of Selected Asteroids: Presentation and Data Analysis Considerations", submitted to *Icarus*.

Vilas, F., Hatch, E., Gaffey, M., and Larson, S. (1991). "Aqueous Alteration Products in the

Reflectance Spectra of Primitive Asteroids", *BAAS*, v. 23, 1139.

Hatch, E., Vilas, F., Larson, S., and Gaffey, M. (1991). "A 0.43- μm Absorption Feature in C-Class Asteroid Reflectance Spectra", *BAAS*, v. 23, 1138.

Astrometric Observations of Comets and Minor Planets

Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Drive
Pasadena, CA 91109

J. G. Williams and J. Gibson

Strategy

Comets and asteroids have been observed with the Palomar 1.5 m telescope using a CCD array. The goal is positions of astrometric quality and the priorities are comets plus minor planets which are planet crossers, Trojans, Hildas, have high inclinations, or otherwise have unusual orbits. The stress was on recoveries of comets and asteroids seen at previous oppositions and follow up on newly discovered objects. Since asteroids are usually discovered near perihelion when bright, the next several opportunities for recovery are normally fainter. Thus big telescopes complement discoveries by smaller instruments.

Progress and Accomplishments

The priority this year was the measurement and reduction of CCD frames. Two examples of the value of well placed positions follow. 1988 TJ1 is an Amor asteroid ($q = 1.14$ AU) with a diameter of roughly 1 km. This object had been observed to lengthen the original three week arc and measurements of the CCD frames provided a three month arc. The longer arc permitted recovery by two other observatories. The two opposition orbit resulted in a third opposition from one of those observatories. The object has now been numbered 4947. The second example is 1988 RE, a crosser with $q = 1.36$ AU. The measurement of positions has extended the former three week arc to four months. This longer arc should permit recovery.

Anticipated Accomplishments

The CCD observing program will be shifted to the 1.2 m Table Mountain instrument. The program will recover faint comets and minor planets and their positions will be measured and reduced. The priorities will emphasize first opposition follow up and second opposition recovery. Comets and planet crossing and other unusual asteroids will be given priority. This is not a survey program.

Publications

Comet and asteroid positions are reported on Minor Planet Circulars.

Physical Studies of Small Asteroids, Cometary Cores and Galileo Targets 243 Ida and 951 Gaspra

Lunar and Planetary Laboratory Space Sciences Building
University of Arizona
Tucson, AZ 85721

Wieslaw Z. Wisniewski

Strategy

The importance of collisional evolution of minor bodies has been increasingly recognized. To reconcile the observed physical properties of those bodies with models and laboratory experiments is a major challenge to asteroid science. The overall research objective is to provide new information on physical properties of small asteroids and cometary cores. This work comprises photoelectric and CCD photometry of asteroids in the 0.1-25 km range and cometary cores. Whenever possible, UBVWX colors are obtained to define taxonomic classes.

Progress and Accomplishments

Approximately 90 nights have been scheduled in support of this work. The observations are made mainly on the 60" and 90" telescopes of the University of Arizona Observatories on Mt Lemmon and Kitt Peak. Twenty two asteroids were observed, four of them Earth-approaching. Galileo target 951 Gaspra was monitored on 6 nights from Arizona and on 6 nights from the South African Observatory at Sutherland. Those last observations were of particular interest, as they were obtained when Gaspra was close to 0 phase angle (0.5 degree). There was no opposition surge, but rather a normal 0.25 mag increase in brightness, as determined from a linear regression. The CCD images useful for astrometry were immediately delivered to the Galileo imaging team. A collective paper on Gaspra's "Pre - Galileo model" was prepared and submitted to *Icarus* before the Galileo - Gaspra encounter.

Anticipated Accomplishments

I propose to continue physical observations (taxonomy and light-curves) of small asteroids and cometary nuclei. The impressive discoveries by Spacewatch of bodies much smaller than 1 km in diameter require almost immediate follow-up. I successfully did such observations, being guided by the Spacewatch observer almost shortly after the discoveries of 1989 UP, 1990 UP, 1991 EE, and 1991 VG. As there is a chance that Galileo will image 243 Ida, extensive ground-based coverage shall be conducted to define the physical characteristics such as shape, taxonomy, albedo variegation and pole orientation before the encounter.

Publications:

Physical Studies of Small Asteroids. W. Z. Wisniewski, 1991, *Icarus*, **90**, 117.

The Unusual Light-curve of 1990 TR. W. Z. Wisniewski, 1991, *Asteroids, Comets, and Meteors 1991*. Editor A. Harris. In press.

The Shape of Asteroid 1917 Cuyo. S. J. Ostro and W. Z. Wisniewski, 1991, *Asteroids, Comets, and Meteors 1991*. Editor A. Harris. In press.

Asteroid 951 Gaspra: Pre-Galileo Physical Model. P. Magnusson et al., 1991, *Icarus*. in press.

Comet and Asteroid Dynamics

Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, California 91109

Donald K. Yeomans

Strategy

In order to provide the ground-based observing community and NASA flight projects with accurate comet and asteroid ephemerides, improvements are being made to the existing dynamic models and new data types are being investigated. For active comets, nongravitational forces must be taken into account; these forces are assumed due to the rocket-like thrusting of outgassing cometary ices.

Progress and Accomplishments

For the 30 asteroids and 4 comets for which radar data are available, orbits have been computed using both the radar and existing optical measurements. The precise techniques required to process radar data were developed and published so that other orbit computation centers can take advantage of the powerful nature of the radar data. For the period from August 1991 through December 1996, all of the comets and asteroids passing closer than 0.3 AU to the Earth were identified and the circumstances published so that future observing campaigns can be planned. During 1991-1992, orbit improvements were computed and radar ephemeris predictions provided for asteroids 4 Vesta, 7 Iris, 324 Bamberga, 1981 Midas, 1982 BB, 1991 EE, 1991 JX, and 1991 VG. Radar ephemeris predictions were also provided for Mercury, Saturn, and Titan. Ephemeris information for approximately two dozen comets and asteroids were provided to optical observers both outside of, and within, the NASA community. To facilitate observation planning and mission design work, cometary observing circumstances were published for the 1990 - 2010 interval.

Anticipated Accomplishments

Accurate orbits and ephemerides will be generated in support of optical and radar observations of comets and asteroids. Particular emphasis will be given to the Dec. 1992 close-Earth approach of asteroid 4179 Toutatis. The extensive asteroid ephemeris development effort for the successful flyby of 951 Gaspra by the Galileo spacecraft will be detailed.

Publications

Yeomans, D.K. (1991). "Cometary Orbital Dynamics and Astrometry", *Comets in the Post-Halley Era*, edited by R.L. Newburn, Jr., M.M. Neugebauer, and J.H. Rahe. *Kluwer Academic Publishers*, vol. 1, pp. 3-17.

Yeomans, D.K. and Wimberly, R.N. (1991) "Cometary Apparitions 1990 - 2010", *Comets in the Post-Halley Era*, edited by R.L. Newburn, Jr., M.M. Neugebauer, and J.H. Rahe. *Kluwer Academic Publishers*, vol. 2, pp. 1281-1308.

Ostro, S.J., Campbell, D.B., Chandler, J.F., Shapiro, I.I., Hine, A.A., Velez, R., Jurgens, R.F., Rosema, K.D., Winkler, R. and Yeomans, D.K. (1991) "Asteroid Radar Astrometry", *Astronomical Journal*, **102**: 1490-1502.

Yeomans, D.K., Chodas, P.W., Keesey, M.S., Ostro, S.J., Chandler, J.F., and Shapiro, I.I. (1992). "Asteroid and Comet Orbits Using Radar Data", *Astronomical Journal*, **103**: 303-317.

HIGHLIGHTS OF RECENT ACCOMPLISHMENTS

Ices on Neptune's Satellite Triton

Dale P. Cruikshank

Triton is Neptune's largest satellite, and astronomical observations have shown us that its surface is covered by at least four kinds of ice. At Triton's surface temperature of 38 K nearly everything that we commonly regard as a gas or liquid is frozen solid. Thus, frozen methane and nitrogen were discovered by infrared spectroscopy in the late 1970s and 1980s, and were confirmed by the results of the Voyager flyby in 1989. Voyager also gave striking images of the tortured surface of Triton with its highly varied and fractured terrain. Voyager found clouds and haze in the satellite's atmosphere, and "geysers" that spout gases and solids from the surface high into the thin atmosphere.

D. P. Cruikshank and his colleagues* have recently discovered monoxide and carbon dioxide ices on Triton's surface through infrared spectroscopy with large Earth-based telescopes. These molecules are important in understanding the chemistry of the formation and subsequent evolution of Triton, as well as in puzzling out the details of the satellite's thin atmosphere. Analysis currently in progress will help shed light on the seasonal effects on the icy surface and cold atmosphere of Triton, thus laying groundwork for possible future missions to the Neptune system.

References

T. C. Owen, T. Geballe, C. deBergh, R. H. Brown, J.
P. Maillard, B. Lutz, B. Schmitt

PRECEDING PAGE BLANK NOT FILMED

Discovery of Solar-System Objects by CCD Scanning

T. Gehrels

Spacewatch continues to find new types of objects, as can be seen in the Table. The discovery of 1991 VG drew great attention. The *New York Times* carried an article about it, and that was followed by articles, talk shows and TV news in the U.S. and abroad. It may be an upper stage of a spacecraft, or, if natural, a new type of asteroid, with orbit nearly the same as that of Earth. There is an unexpectedly large population of small objects among the near-Earth objects. Regarding the large objects found, the discovery of both asteroids 5145 and 2060, within a short interval of observing, indicates that there is a population of such objects out there, near the orbits of Saturn, Uranus, and Neptune. The orbit of 5145 is chaotic: a chance proximity to any of the outer planets can change the orbit drastically, with the possibility of making it even a near-Earth object.

Identification Remarks	Perihelion distance (AU)	Aphelion distance (AU)	Incli. nation (deg)	Dia- meter (km)	Date of Discovery	
P/Spacewatch CCD discovery comet	1.58	4.5	9.5	-	10 Sep.,1991	first of a
1991 RJ2	1.26	2.7	9.0	0.7	2 Oct.,1991	
1991 TT	1.00	1.4	14.8	0.03	6 Oct.,1991	
1991 TU small one	0.94	1.9	7.7	0.009	7 Oct.,1991	another
1991 VA	0.93	1.9	6.5	0.02	1 Nov.,1991	
1991 VG smallest one so far	0.97	1.1	1.6	0.008	6 Nov.,1991	
1991 XA	0.98	3.6	5.3	0.09	3 Dec.,1991	
1992 AD asteroid 5145	8.7	32.2	24.7	140	9 Jan.,1992	
1992 AE	1.24	3.2	6.4	3.3	10 Jan.,1992	Amor
1992 BA	1.25	1.4	10.5	0.4	27 Jan.,1992	
1992 DU	0.96	1.4	25.1	0.05	26 Feb.,1992	Apollo

In addition to the discoveries, Spacewatch rediscovered 3288 (an Apollo), 3122 (an Amor), P/Shoemaker-Levy 5, P/Gunn and (2060) Chiron (!), and made the first detection with a ground-based telescope of a cometary dust trail (of P/Faye). 1991 RJ2 had been discovered by Helin in September, but it was then lost. We also obtained preliminary orbits for objects that looked promising, namely 1 Trojan, 1 Hilda, 1 Flora, 5 Mars-Crossers and 3 Hungarias.

**Palomar Planet-Crossing Asteroid Survey (PCAS)
1/1991 - 3/1992E.**

F. Helin

PCAS continues to make major gains in the discovery of Near-Earth Asteroids (NEA'S) as well as other classes of asteroids related to the evolution of objects into planet-crossers. Sky coverage of 53,000 sq. degrees has led to the discovery of 17 Near-Earth Asteroids (NEAs), 2 Atens, 8 Apollos and 7 Amors, in the last 14 months, an unprecedented number of discoveries in such a short period. This high discovery rate reflects still greater sky coverage, improvement in focus and threshold detection. In addition, 275 other asteroids of all classes were discovered, reported and given designations including 45 high inclination asteroids (24 Hungarias and 21 Phocaeas). Although we continue to discover bright NEAs, we have found 6 small NEAs with absolute magnitude 19 or higher. This indicates a greater sampling of the smaller sized objects in the NEA population. 28 asteroids have been permanently numbered and another 14 previously numbered have been officially named. Of the newly numbered, four are NEAs. The most accessible asteroid, 1991 JW was discovered in May 1991. With its Earth-like orbit, it's observable for extended periods of time, allowing excellent opportunities for acquiring physical observations. 1991 JW appears to be a somewhat better mission candidate than (4660) Nereus, another PCAS discovery. Several excellent candidates with low delta V were discovered for future spacecraft missions. Another exciting object, 1984 QY1, recently found on old films, has an extremely eccentric orbit which travels inside the orbit of Mercury to approaching the orbit of Saturn. As co-investigator of target of opportunity under the "Exceptional Solar System Object", the Hubble Space Telescope successfully imaged the unusual object 1992 AD on 27 April. In addition, PCAS discovered three new parabolic comets in the past 14 months. Two of these comets are distant, 1991r and 1992a, making their closest approach to the Sun at a distance of 4.85 A.U. and 3.01 A.U. respectively. Rarely are comets discovered with small telescopes at these large distances.

PCAS' rate of discovery in 1991/1992 continues to yield a dozen or more NEAs per year.

Continuing progress is anticipated in the automated identification and measurement procedures. Plans are in progress to upgrade to a CCD array to be retrofitted on the 0.46 m Schmidt. Our major thrust will be the conversion to a CCD camera system as promptly as possible.

A Detailed Map of Titan's Stratosphere from Stellar Occultation

W. B. Hubbard

Saturn's largest satellite Titan occulted the bright K giant star 28 Sgr on 3 July 1989, in perhaps the best-observed planetary occultation in history, with very substantial fractional coverage of the occultation shadow, high time resolution and high signal/noise, and excellent range in wavelength. Fortuitously, the center of the shadow passed over the most densely populated parts of Europe. This unusual event was observed by professional and amateur astronomers at stations in Great Britain, Germany, France, Italy, Israel, and Uzbekistan, including temporary stations supported by NASA's Planetary Astronomy program. The resulting chords across Titan's shadow have impact parameters to the shadow center ranging from 200 km north of the center to more than 2000 km south of the center. Since total radius of Titan's occultation shadow is nearly 3000 km, almost 50% of the shadow was covered with chords, at an average spacing of about 200 km. An international cooperative analysis effort involving NASA-supported planetary scientists in the USA and numerous scientists in Europe and Israel has resulted in the construction of an enormous incomplete raster image of Titan's occultation shadow, with transverse and vertical dimensions of about 6000 km and 2500 km respectively. The image is also multicolor, spanning wavelengths from 0.36 micrometers (UV) to 0.89 micrometers (near-IR).

The image scans the detailed structure of Titan's atmosphere in an altitude range from 250 to 450 km, providing the distribution of temperature, pressure, haze optical depth, and zonal wind velocity. Dense haze layers appear in Titan's stratosphere at altitudes of about 300 km, at a pressure of only 1/10 millibar. In 1989, during midsummer in Titan northern latitudes, the haze layers were substantially denser than those seen by Voyager in 1981. The dense haze abruptly terminates at a "break line" located at -20 degrees Titan latitude, and the southern winter portion of Titan's atmosphere is clearer. The haze reddened the starlight, and analysis of this effect indicates that haze particles have radii of about 0.1 micrometers.

Analysis of the central flash, an effect which is produced by global focusing in Titan's atmosphere, yields measurements of wind speeds in the stratosphere. The observations indicate zonal flows much faster than the rotation of Titan's surface, with speeds of about 150 meters/sec at high latitudes, and about 80 meters/sec near the equator. The spin state of Titan's solid surface is unknown as it is veiled by clouds, but the occultation data show that Titan's atmosphere is symmetric about an axis which is aligned with the spin axis of Saturn. It is therefore very probable that Titan's body spin vector is aligned with Saturn's.

Plasma Flow in the Coma of Comet Halley

M. Neugebauer,
B. E. Goldstein, and R. Goldstein

The Giotto spacecraft carried two different instruments - the Johnstone Plasma Analyzer (JPA) and the Ion Mass Spectrometer (IMS) - for the observation of hot ions in the coma of P/Halley. Although there are many similarities in the time and distance profiles of the plasma flow parameters (i.e., the bulk velocity, density, and temperature) computed from the two data sets, there are also some significant differences, especially at cometocentric distances $< 500,000$ km. The principal discrepancies between the JPA results presented by Formisano et al. (1990) and the IMS data analyzed by our group are: (1) The IMS did not detect the levelling off of the speed and temperature profiles that Formisano et al. interpreted as "flow stabilization". We believe the apparent constant speed reported in the inner coma was due to the limited range of the JPA instrument. (2) The IMS detected differential north-south flow between the solar wind and cometary ions for only a brief interval when the magnetic field was oriented nearly southward, whereas Formisano et al. reported more extensive north-south differential flow that was independent of the direction of the field and therefore much more difficult to explain. (3) The JPA densities were factors of 2 to 4 higher than the IMS densities which, in turn, were an order of magnitude greater than theoretical values. Although some additional source of ionization is required in the theoretical models, the IMS data do not support Formisano et al.'s contention that the critical ionization velocity phenomenon was an important source of ionization in the coma of P/Halley.

Reference: V. Formisano et al., *Astron Astrophys.*, 238, 401, 1990.

Infrared Observations of Planetary Atmospheres

Glenn S. Orton

A high-resolution echelle grating array spectrometer has been used to create spectral images of Jupiter in the thermal infrared. Among the results of these observations, performed in collaboration with John Lacy (University of Texas, Austin) at the NASA/Infrared Telescope Facility, we found unexpected levels of enhanced emission from discrete locations on the disk. These locations, near both north and south poles, are associated with regions in which auroral phenomena have been observed by Voyager and the International Ultraviolet Explorer, and - at the south pole - they may also be associated with regions of enhanced emission by the H_3^+ radical and neutral H_2 in the near infrared. The enhanced emission was seen first in methane (CH_4) lines, corresponding with older observations at much lower resolution; these measurements indicate that the regions are characterized by enhanced stratospheric temperatures, as CH_4 is well mixed in the relevant part of Jupiter's atmosphere. Observations in October of 1989 showed enhanced emission from stratospheric acetylene (C_2H_2) and ethane (C_2H_6) at the north pole near 180 degrees longitude (in System III, which is associated with the rotation of Jupiter's interior), coincident with the location of enhanced stratospheric temperatures. At the same time, enhanced stratospheric ethylene (C_2H_4) emission was observed near the south pole and 330 degrees longitude. In December of 1991 and February of 1992, enhanced emission was observed from C_2H_2 , C_2H_4 and C_2H_6 near the south pole at 60 deg. longitude. It is strongly suspected that the enhanced emissions and the unusual chemistry are the result of high-energy particles associated with Jupiter's powerful magnetic field impinging upon the atmosphere in these particular locations. The reason for the relatively constant properties of the north polar "hot spot" and the variable properties of the south polar "hot spot" are unknown at this time. The nature and time dependence of these emissions will be explored in future observations and theoretical work.

High-Resolution Radar Ranging to Near-Earth Asteroids**S. J. Ostro**

Radar delay/doppler astrometry permits significant refinements of orbital elements and commensurate improvements in the accuracy of prediction ephemerides because the measurements have fine fractional precision and are orthogonal to optical, angular-position measurements. For newly discovered near-Earth asteroids, whose orbits must be estimated from optical astrometric data that span short arcs, a few radar observations can mean the difference between successfully recovering the object during its next close Earth approach and losing it entirely. However, even for a numbered near-Earth asteroid with a secure orbit, a few delay/doppler measurements can shrink the positional error ellipsoid by a factor of two for at least a decade (Yeomans et al. 1987, *Astron. J.* 94, 189). Most of the pre-1991 asteroid radar astrometry appears in Ostro et al. (1991, *Astron. J.* 102, 1490). Yeomans et al. (*Astron. J.* 103, 303) describe procedures for incorporating such data in orbit estimations and give orbits for 34 targets based on the combined radar and optical data.

Between July 1990 and June 1991, we made high-resolution radar observations of three objects shortly after they were discovered by E. F. Helin et al. All three experiments yielded time delay astrometry with resolution less than or equal to 1 microsecond (range resolution less than or equal to 150 meters). Examples are shown below. Epochs refer to the instant of reception of the peak of the echo power distribution at the telescope reference point, which for Arecibo (A) is the center of curvature of the telescope's main reflector and for Goldstone (G) is the top of the antenna cone. Quoted uncertainties equal the waveform's time resolution, i.e., its basic modulation interval.

Target	UTC epoch, hh:mm	Obs.	Time delay, microsecond
1990 MF	1990 Jul 09, 09:40	G	$33,140,417.9 \pm 0.4$
1991 AQ	1991 Jan 30, 19:06	A	$70,481,150.8 \pm 1.0$
1991 JX	1991 Jun 05, 03:00	A	$47,132,018.6 \pm 1.0$
1991 JX	1991 Jun 05, 03:20	A	$47,082,319.3 \pm 0.4$
1991 JX	1991 Jun 07, 03:40	A	$40,481,934.8 \pm 0.2$
1991 JX	1991 Jun 15, 08:40	G	$37,539,518.3 \pm 0.4$

The fractional precision of Arecibo's 0.2-microsecond astrometry is five parts in one billion. Such measurements, as well as delay-doppler imaging with 30-meter resolution, should become routine upon completion of instrumentation upgrades now underway.

Near-Infrared Windows in Titan's Atmosphere

Tobias Owen

One of the few disappointments among the many great triumphs of the Voyager mission was the inability of the cameras to see the surface of Titan. The thick atmosphere of this satellite (surface pressure 1.5 bars) is filled with a photochemical smog that completely hides the surface from view in visible light. This is especially frustrating since Titan's landscape may include such exotic features as lakes or even seas of liquid hydrocarbons and drifts of organic sediment in addition to the impact craters we expect to find. Channels resulting from erosion of the ice-covered surface by organic liquids may also be there, and it is possible that there are active vents or "geysers", from which the atmosphere is continually resupplied. But these conjectures will remain nothing more than that until we obtain some real data on surface properties. Prospects for such information have improved with the discovery that there are regions in Titan's spectrum in the near-infrared where the ubiquitous haze is relatively transparent and the absorption from atmospheric methane is weak or non-existent. At these wavelengths, it should be possible to see the lower atmosphere (where methane condensation clouds are expected) and possibly the surface as well.

This discovery was made by means of observations of Titan's spectrum with the NASA Infrared Telescope Facility on Mauna Kea, Hawaii, using a Cooled Grating Array Spectrometer. The brightness of the satellite at 1.3, 1.6 and 2.0 mm was shown to result from the absence of methane absorption and the relative transparency of the haze at these wavelengths. Models of the atmosphere that reproduce the appearance of the spectrum must include very long pathlengths through the atmosphere to match the observed intensities of weak methane bands at these wavelengths. It is not possible from these observations alone to be certain that the reflected sunlight we observe is actually coming from the surface itself or from some low-lying cloud bank. If it is the surface, then the most likely surface candidate is dirty water ice. A global ocean of hydrocarbons is excluded. Future observations should clarify this situation; imaging with array cameras may reveal the presence of tropospheric clouds, even from Earth. If our interpretation of the data is indeed correct, it suggests that the near IR spectrometer on the Cassini orbiter should be able to view the surface of Titan through these windows, allowing studies of topography and atmospheric circulation. Even the Cassini camera should be able to glimpse Titan's troposphere at the long-wave end of its useful range.

Sodium and Potassium in the Lunar Atmosphere

A.E. Potter

Our discovery that sodium and potassium vapor can be observed in the lunar atmosphere using ground-based telescopes has opened up a field of investigation that was closed after the last Apollo mission to the Moon. The Apollo measurements showed that the Moon does have a detectable atmosphere, but left a number of questions unanswered. We can now investigate the lunar atmosphere, or at least a component of the lunar atmosphere, on the daylit side of the Moon at all lunar phases. Our ground-based measurements of sodium and potassium vapor showed that the lunar atmosphere extends to great heights. We detected sodium at altitudes up to 1500 km. above the surface, and it certainly must extend even higher. This implies a high effective temperature for the sodium, of the order of 1000 K or more. We tested the effect of solar wind by measuring the sodium exosphere before and after the Moon entered the Earth's magnetotail, where direct solar wind is absent. There was little difference between the two cases, which supports the idea that the sodium exosphere is maintained by solar radiation. The great size of the sodium exosphere makes it difficult to map adequately with single point measurements, as we have done in the past. We now plan to use a solar coronagraph to block out direct moonlight, and to image the sodium exosphere on a CCD detector. In this way, we can get images of the entire exosphere, in order to better understand its nature.

Potter, A. E. and T. H. Morgan, (1991), "Observations of the Lunar Sodium Exosphere". *Geophys. Res. Lett.* 18, 2089-2092.

Fast 'Jets' from Io's Atmosphere Explained

Nicholas M. Schneider

Jupiter's moon Io loses about a ton of sulfur and oxygen from its atmosphere every second, an indirect result of Io's astonishing volcanic activity. Our work has discovered an important way in which the atmosphere is stripped away.

Our groundbased observing program images the million-kilometer-wide field around Jupiter, including Io's orbit. We use the 1.5 meter telescope at Catalina Observatory near Tucson, Arizona, with a CCD camera. Our instrument (built by John Trauger, JPL) contains filters and masks specially designed to detect faint emissions close to such a bright object as Jupiter.

The observations showed bizarre jets emanating at Io but looping all the way around Jupiter. These features changed rapidly, implying very high velocities. Extensive modelling had led us to the conclusion that this kind of sodium escape is fundamentally different from previously proposed mechanisms. We suggest that the neutrals in these unusual patterns were recently molecular ions. The ions were released from Io, and swept downstream by Jupiter's magnetic field. When the ions neutralize, they come apart and the fragments fly away from Jupiter at velocities of tens of kilometers per second. These neutrals scatter sunlight, and can be detected with groundbased telescopes. Only molecules neutralize fast enough to explain the observed features.

Our strong conclusion (that molecules are required) goes contrary to prior atmospheric simulations. We are currently working on new atmospheric models. The plasma/atmosphere interaction is a critical link in understanding how mass and energy are supplied to the magnetosphere, and may also help reveal what process stabilizes this complex system in the face of variable volcanic activity on Io.

N.M. Schneider, J.T. Trauger, J.K. Wilson, D.I. Brown, R.W. Evans, D.E. Shemansky: "Molecular Origin of Io's Fast Sodium", *Science* 253, 1394 (1991).

Radar Studies in the Solar System

Irwin I. Shapiro

We have actively engaged in observations of asteroids and comets, both as systematically planned targets and as "targets of opportunity." The most recent examples of the latter are asteroids 1991 EE, which was discovered optically on 1991 March 13, and 1991 VG, which was found on 1991 November 6. 1991 EE's closest approach to the Earth in 1991 was not until six months after discovery, so that scheduling time on the Arecibo radar was a relatively routine matter, as were the preparation of ephemerides and the observations themselves; in contrast, the best time for observing 1991 VG at Arecibo would have been the very day of discovery. The object was so dim optically, that, despite its close approach to the Earth, its likelihood of radar detectability was presumably small, and it would not have merited a concerted effort, except for its unusual, very Earth-like orbit. Such an orbit suggested that 1991 VG was either a representative of a hitherto unknown class of asteroids or a piece of debris from a space launch. Due, in part, to our previous success in obtaining useful radar data on short notice, we and our colleagues were able to schedule time on the Arecibo radar for observing 1991 VG, but no clear echoes were obtained. Indeed, no further successful optical observations have been made of the object, and its origin remains as uncertain as before. For 1991 EE, on the other hand, the radar observations were successful and yielded both delay and Doppler measurements. With further processing, the results of the observations are expected to include information on the asteroid's surface properties, size, shape, and spin.

The observing program also covered other asteroids, two of the four Galilean satellites of Jupiter, and the planet Mercury. We are gaining understanding of the surfaces of both rocky and icy bodies from analysis of these results. The most recent radar observations of Ganymede and Callisto (satellites of Jupiter) yielded, for the first time, round-trip delay measurements and are expected to provide an equivalent range to the Jovian system that will be useful in guiding the Galileo spacecraft. Also, analysis of newly available radar observations of Venus has led to a refinement of the spin vector of that planet and has thereby provided a coordinate basis for the Magellan spacecraft mapping mission.

This work was carried out through a collaboration involving SAO, NAIC (Arecibo and Cornell), and JPL, including D.B. Campbell, J.F. Chandler, J.K. Harmon, S.J. Ostro, I.I. Shapiro, and M.A. Slade, among others.

Bistatic Radar Observations of Asteroids

E. Snyder

On Sept. 9, 1991, we used the VLA to receive radar returns from the asteroids 1991EE and Bamberga. The X-band radar signal was transmitted by the 70m Deep Space Network antenna at Goldstone, California. On Sept. 13 we reobserved Bamberga and 1991EE, and on Sept 16, we observed Iris. Only the data for Sept 9 have been studied carefully yet, as software development has been necessary to correct the data for the phase errors caused by these objects being in the near field of the VLA A-array.

Radar alone provides excellent information about the position and motion of the objects along the line of sight; by receiving the return with the VLA, we determine the position in the plane of the sky and expect to resolve details of the objects as well. Bamberga is a relatively large asteroid (diameter = 242 km) which was about 0.8 AU from the earth when observed on Sept. 9. Therefore, the near-field effect, although important, does not completely blur out images. Figure 1 shows the most fully processed image of Bamberga to date. It uses all of the Sept. 9 data and has 0.49×0.45 arcseconds resolution. Bamberga is displaced 1.99 ± 0.06 arcseconds East and 0.65 ± 0.02 arcseconds North from the ephemeris position derived from optical observations made between 1905 and 1985. Its apparent size is 0.39×0.23 arcseconds (position angle 152 degrees). A 240 km diameter disk at the distance of Bamberga during these observations would subtend 0.41 arcseconds. Thus within the uncertainties of the diameter measurement, the radar measurements agree with the diameter deduced from optical studies. This is consistent with the expectation that an object of this size will be very rough so that specular reflection will not give a bright point at the sub-radar point on the disk (as is seen in planetary observations).

High-Resolution Infrared Imaging of Io's Volcanic Activity

John R. Spencer

Since October 1990 we have observed 19 eclipses and occultations of Io by Jupiter using a 1-5 micron infrared camera at the NASA Infrared Telescope Facility on Mauna Kea. We typically obtain an angular resolution of 0.5 - 0.3 arcseconds. At least 2 hotspots (sometimes 4 or 5) are normally resolvable at 3.5 - 4.8 microns, allowing determination of the location, power, and temperature of each. Even higher spatial resolution, in one dimension and at one wavelength, is routinely attained from photometry of the occultations of Io by Jupiter. These observations document a major outburst of Loki between December and April 1991, and its low level of activity (down by a factor of 10 at 3.8 microns) before and ever since that event. They also show very constant activity at the hot spot "Kanehekili", the second brightest hot spot on the Jupiter-facing hemisphere of Io, between December 1989 and April 1991, but a drop in activity by October 1992. Some smaller spots show stability over a year, while others appear for only a few weeks.

Disk-integrated observations of Io in Jupiter eclipse at 2.2 and 1.6 microns allowed the temperature of the hottest parts of the hot spots to be measured. These observations show that several square km at about 800 K, much too hot for liquid sulfur, are usually present on Io's surface. Landsat observations of thermal emission at the same wavelengths from the andesitic Andean volcano Lascar have roughly comparable color temperatures, showing that the short-wavelength Io emission is at least consistent with silicate volcanism.

Extraordinary Colors of (5145) 1992 AD

David J. Tholen,
Beatrice E.A. Mueller (Post-Doc for M. Belton)
William K. Hartmann, and Dale P. Cruikshank

(5145) 1992 AD was discovered on UT January 9, 1992 by D.L. Rabinowitz with the Spacewatch telescope on Kitt Peak (Scotti 1992). VRI colorimetry was taken the same night at the KPNO 2.1m telescope by Mueller and BVRI measurements by Tholen on January 23 (Mueller 1992, Tholen 1992). The object was found to be far redder than any other asteroid and comet previously observed bringing new excitement and scientific interest into asteroid and comet research. The red color of (5145) 1992 AD may be associated with exposure of organics that are purer or more pristine than those found on the surfaces of CPD asteroids and comets.

Comparing the reflectivity of this object to CPD asteroids made it clear that the CPD scenario is not a complete description of outer solar system bodies. It was predicted by Bell et al. (1989) that redder objects will be found in the outer solar system. However it is too early to state that (5145) 1992 AD confirms the trend of increasing formation efficiency of colored organic compounds (or decreasing destruction efficiency) as function of solar distance because we don't know its point of origin.

We also compared the reflectivity to laboratory samples of materials believed to be likely found on asteroids (Cruikshank et al., in preparation). Most of the 'traditional materials' (carbonaceous and silicate rocks and minerals and ices) are too blue compared to (5145) 1992 AD. Organic substances in low-albedo mixtures like asphaltite and tholins seem to match the measured colors of the object much better (Mueller et al. 1992). Fink et al. (1992) came to a similar conclusion in an independent paper.

References:

Bell, J.F., D.R. Davis, W.K. Hartmann, and M.J. Gaffey 1989. Asteroids: The big picture. In *Asteroids II* (Binzel, Gehrels, Matthews, Eds.) pp.921. Univ. of Ariz. Press, Tucson

Fink, U., M. Hoffmann, W. Grundy, M. Hicks, and W. Sears 1992. The steep red spectrum of 1992 AD: An asteroid covered with organic material? submitted to *Icarus*

Notes, Mueller, B.E.A. 1992. 1992 AD. *IAU Circ.* 5434

Mueller, B.E.A., D.J. Tholen, W.K. Hartmann, and D.P. Cruikshank 1992. Extraordinary colors of asteroidal object (5145) 1992 AD. submitted to *Icarus*

Notes, Scotti, J.V. 1992. 1992 AD. *IAU Circ.* 5434
Tholen, D.J. 1992. 1992 AD. *IAU Circ.* 5434

Ground-Based Observations Provide Preview of Galileo Encounter With Gaspra

D. J. Tholen

Simultaneous ground-based observations of the reflected light and thermal emission from 951 Gaspra on 1991 May 18 yielded an effective diameter of 12.8 km and a visual geometric albedo of 0.22. The observations were obtained by D. J. Tholen, T. M. Herbst, and W. F. Golisch using the University of Hawaii 2.24-m telescope and the NASA Infrared Telescope Facility on Mauna Kea. When corrected for aspect and shape, the data suggest dimensions of approximately 16 by 11 by 11 km, though the lightcurve indicates that the asteroid is not as symmetric as these numbers might suggest. When the recent observations are combined with others made at different points in Gaspra's orbit, the data show the asteroid to have a spin axis that is tilted rather substantially, perhaps at much as three times that of the Earth. These observations were used to plan the Galileo encounter with the asteroid.

Discovery of New Asteroid Class

D. J. Tholen and B. E. A. Mueller independently discovered that 5145 1992 AD, found on 1992 January 9 by D. L. Rabinowitz using the Spacewatch telescope on Kitt Peak, has a reflectance spectrum between 0.4 and 0.9 microns that is nearly twice as red as the reddest previously known asteroid or comet. The asteroid was singled out for special attention because of its unusual orbit, which carries it from just inside Saturn's orbit to just outside Neptune's, making it the most distant known asteroid in the Solar System. The spectrum is best matched by laboratory materials that are rich in organic substances. In recent years, several attempts have been made to observe absorption features in asteroid spectra due to organics, but only marginal detections have been reported so far. 1992 AD represents the best candidate yet for a convincing detection of organic absorption features in asteroid spectra, and such observations are planned for the next opposition in early 1993. In the meantime, a new taxonomic class has been created to designate the unique spectrum of this intriguing object.

Discovery of H₃⁺ on Uranus

L. Trafton

L. M. Trafton, T. R. Geballe, and S. Miller report the discovery of H₃⁺ on Uranus on April 1, 1992 UT. The observations were made with the CGS4 spectrometer on the UKIRT telescope. The strongest lines were detected after 4 min of integration. In total, eleven lines of the H₃⁺ fundamental band between 3.90 and 4.07 microns, primarily from the Q branch, were detected in emission with S/N ratios better than 5. The peak S/N ratio was 20 and occurred for the Q(3) bend at 3.987 microns. The flux in this line was about 9×10^{-17} W/m² in a 3" slit centered on the planet. Uranus is the second planet for which H₃⁺ line emission has been detected, following the original detection in Jupiter in 1988. The significance of this detection is that auroral phenomena on Uranus, previously observable only from space, can now be studied from ground based observatories.

Discovery of Another Unidentified Absorption Feature in Io's K-Band Spectrum

D. F. Lester, L. M. Trafton, T. F. Ramseyer, and N. I. Gaffney report the detection of an absorption feature at 1.98 microns in Io's spectrum. This is only the second unidentified feature discovered in Io's K-band spectrum. The first is the absorption feature at 2.125 microns. The strength and width of these features is comparable, suggesting that they may belong to the same class of source material. CO₂ clusters has been suggested as the source of the 2.125 micron feature but no definitive identification has been made. Neither feature appears to vary with orbital longitude or time, in contrast to other known absorptions on Io. Observation of the 2.125 micron feature during the 1991 mutual events involving Io show that the source material is not frozen out over Io's poles, but is nearly uniformly distributed over the disk, with local concentrations at low latitudes. These features are significant because they provide new information on the interaction of Io's atmosphere, surface, and volcanic activity.

Occasional H₂ Dimer Emission on Jupiter

L. M. Trafton and J. K. G. Watson have analyzed rare global-scale emission events on Jupiter as emission from the excited H₂ dimer. The presence of the H₂ dimer in absorption has been known since Voyager observations of Jupiter, but no H₂ dimer emission has been previously reported. Unlike the auroral emissions of H₂ quadrupole lines and H₃⁺, the dimer emission is not confined to the magnetic polar arcs, but extends to low latitudes with significant strength. Their occurrence suggests incidences of unusual magnetospheric loading, perhaps associated with unusual activity of Io or the solar wind.

Compositional Studies of Primitive Asteroids

F. Vilas

Primitive asteroids in the solar system (C, P, D class and associated subclasses) are believed to have undergone less thermal processing compared with the differentiated (e.g. S class) asteroids. The S-class asteroids comprise the majority of the inner main belt and near-Earth asteroid population. The C-class asteroids become the dominant class of the main-belt asteroids beginning at a heliocentric distance of 2.5 AU. The transition of the dominant class of asteroid from the Cs to the P class occurs near 4.0 AU, with the D-class asteroids being the dominant class at the distance of Jupiter's orbit, 5.2 AU. Telescopic spectra of C-class asteroids show effects of aqueous alteration products, produced when heating of the asteroid was sufficient to melt surface water, but not strong enough to produce differentiation. These features include a sharp blue-UV turn over beginning at wavelengths shorter than 0.55 μm - the edge of a sharp UV charge transfer absorption seen in phyllosilicates (clay silicates having a sheet-like texture); absorption features attributed to Fe^{2+} - Fe^{3+} charge transfers in iron oxides present in phyllosilicates located in the visible/near-infrared spectral region; and a deep absorption feature located from 2.6 - 4.0 μm attributed to structural hydroxyl (OH) and interlayer and absorbed water (H_2O) in phyllosilicates.

Absorption features in a suite of main-belt C-class asteroids and some Cybele asteroids show similarities to absorptions seen in laboratory spectra of terrestrial serpentines and chlorites, and laboratory spectra of CM2 carbonaceous chondrite meteorites. The most common feature seen is an absorption feature centered at 0.7 μm , although a new bimodal absorption feature pattern is becoming apparent among the asteroid spectra. Blue-UV spectra of main-belt C-class asteroids were searched for signs of the 0.4- μm Soret band indicative of porphyrins, but none was found. An absorption feature centered at 0.43 μm was identified in these spectra. Absorption features have also been identified in the C- and P-class asteroids in the Cybeles ($a=3.4$ AU) and some of the Hildas ($a=4.0$ AU), however, no analogues exist for these spectra among the spectra of known meteorites. Spectra of 10 additional asteroids, all located in the outer belt, show no indication of these absorption features. These 10 objects include all of the Trojan asteroids (asteroids at the greatest heliocentric distance in this study) and all of the D-class asteroids (asteroids generally considered to have the most primitive composition) studied. These spectra suggest that aqueous alteration terminated in the outer belt and did not operate at the distance of Jupiter's orbit (1). These studies are consistent with observations of the presence or absence of the 3.0- μm water of hydration absorption in the infrared spectra of outer-belt asteroids (2).

(1) F. Vilas and M. J. Gaffey (1989). Phyllosilicate absorption features in main-belt and outer-belt asteroid reflectance spectra. *Science*, v. 246, 790 - 792.

(2) L. A. Lebofsky, T. D. Jones, P. D. Owensby, M. A. Feierberg, G. J. Consolmagno (1990). *Icarus*, v. 83, 16 - 26.

The Use of Radar Data for Improving the Ephemerides of Asteroids and Comets

D.K. Yeomans

Accurate orbits have been determined for the 30 asteroids and 4 comets for which radar astrometric data exists. The techniques required to process radar data in orbit determination solutions have been outlined and future radar observation opportunities for asteroids and comets have been identified. For asteroids and comets that have only short intervals of optical astrometric data, the additional use of only a few radar observations will allow a far more accurate extrapolation of their future motions. In this regard, the use of radar data can often ensure an object's successful recovery at future Earth returns and greatly assist efforts in monitoring the rapidly growing population of known Near-Earth objects - including their future Earth approaches.

Astrometric radar data effectively measures the object's distance and velocity along the observer's line-of-sight and hence these data are complementary to optical, plane-of-sky measurements. Radar data taken during an object's close approach to the Earth are most powerful, and the orbit refinement most dramatic, if the object has only a short optical astrometric history. A case in point is the recovery of asteroid 4769 Castalia (1989 PB) by M. Hartley, S.M. Hughes and R. McNaught at the Anglo-Australian Observatory on May 3, 1990. Using an ephemeris based upon the 65 available optical position measurements over the interval from 1989 August 1 - 24, the predicted and observed positions of the object on May 3, 1990 differed by 37" in right ascension and 23" in declination. Had an orbit been available that included the 6 Doppler and 6 delay measurements, in addition to the optical observations, the predicted and observed positions differences could have been reduced to 1.4" and 0.8."

Radar observation residuals can be typically 1 Hz in Doppler and about a microsecond in round-trip delay time. At the Arecibo transmitter frequency (2380 MHz), these errors correspond to range and velocity errors of 150 m and 6.5 cm/sec. For the Goldstone frequency (8495 MHz), the corresponding velocity error is less than 2 cm/s. The power of the radar data becomes evident when one realizes that radar measurement errors are orders of magnitude smaller than the position and velocity uncertainties inherent in orbits based only upon optical data over short time intervals.

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188	
<small>Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503</small>				
1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE March 1993	3. REPORT TYPE AND DATES COVERED Technical Memorandum		
4. TITLE AND SUBTITLE Reports of Planetary Astronomy - 1992		5. FUNDING NUMBERS		
6. AUTHOR(S) Jurgen Rahe, Editor				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) NASA Office of Space Science and Applications Solar System Exploration Division		8. PERFORMING ORGANIZATION REPORT NUMBER NASA TM-4459		
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) National Aeronautics and Space Administration Washington, DC 20546		10. SPONSORING/MONITORING AGENCY REPORT NUMBER		
11. SUPPLEMENTARY NOTES Technical Memorandum - Code SL				
12a. DISTRIBUTION/AVAILABILITY STATEMENT Unclassified - unlimited Subject Category 89		12b. DISTRIBUTION CODE		
13. ABSTRACT (Maximum 200 words) This publication provides information about currently funded scientific research projects conducted in the Planetary Astronomy Program during 1991, and consists of two main sections. The first section gives a summary of research objectives, past accomplishments, and projected future investigations, as submitted by each principal investigator. In the second section, recent scientifically significant accomplishments within the Program are highlighted.				
14. SUBJECT TERMS Planetary Astronomy satellites planets Planetary Detection asteroids comets			15. NUMBER OF PAGES 148	
			16. PRICE CODE A07	
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT Unlimited	

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

NASA-Langley, 1993